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THE ALTERATION OF PYRITE TO PYRRHOTITE BY ALKALI SULPHIDE SOLUTIONS.[1]

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INTRODUCTION.

OBSERVATIONS on record differ regarding the action of alkali sulphide solutions on pyrite, pyrrhotite, and other metallic sulphides. The earlier researches seem to show that pyrite is dissolved to a considerable extent by these solutions and that the ore-forming constituents in nature might be transported thus as true sulphides.

The solvent action of alkali sulphide solutions on ore-forming sulphides was suggested by S. F. Emmons.[2] Becker[3] found that one part of pyrite dissolved in 1800 parts of 1.5 molal sodium sulphide and formed a deep green solution. C. Doelter[4] reported even a higher solubility. At 80° C., 1.017 grams of the finely powdered mineral lost 5.03 per cent. of its iron content in 50 milliliters of the solution. The mineral was ground to an impalpable powder and some oxidation may have taken place during this operation.

By fusing metal sulphides with sodium sulphide, Freeman[5]

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Emmons, S. F.: Geology and Mining Industry of Leadville. U. S. Geol. Survey Mon. 12, p. 563, 1886.

[3] Becker, George F.: Geology of the Quicksilver Deposits of the Pacific Slope. U. S. Geol. Survey Mon. 13, p. 432, 1888.

[4] Doelter, C.: Einige Versuche über die Löslichkeit der Mineralien. Min. pet. Mitt., N. S. 11, pp. 321–324, 1889–90.

[5] Freeman, Horace: The Genesis of Sulfide Ores. Eng. and Min. Jour., vol. 120, p. 973, 1925.

found that they formed true double sulphides of lower melting point. He was unable to fuse sodium sulphide in an electric furnace, and he gives for the melting points of the other sulphides:

Sulphides	M.P.° C.	Double sulphides	M.P.° C.
PbS	1,130	PbS : Na_2S	650
FeS	1,000	FeS : Na_2S	660
ZnS	1,650	ZnS : Na_2S	620
Cu_2S	1,100	Cu_2S : Na_2S	560

Similar compounds were formed from sulphides of Ni, Co, Mn, Mo, As, Sb, Ag, Au, and Cd. Most of these double sulphides decomposed in water, sodium sulphide dissolving while the metal sulphides remained in suspension, but iron, gold, antimony and arsenic double sulphides were soluble. Iron double sulphide formed a deep green solution. Freeman believed that these double sulphides in nature might be transported in solution until they were decomposed by oxygen, carbon dioxide, or other reagents to form ore bodies. These results and conclusions were in accord with previous studies.

A more recent study has been made by Fred Foreman,[6] in which coarse particles of pure pyrite and pyrrhotite were treated under hydrothermal conditions with different solutions, among them sodium sulphide. He used a solution of 0.1 molal strength and reports little or no action, the pyrite grains remaining untarnished in most of the experiments. This work, seemingly in disagreement with previous investigations, suggests the need of further study before any real conclusions can be drawn. Foreman's experiments, and the interpretation of his results, leave a number of important factors not considered.

The only description that Foreman gives of the sodium sulphide solutions used in his experiments is that they were alkaline or neutral in reaction. Such a description is not very definite. Sodium sulphide is a buffer salt and its solutions, no matter what strength, have a definite hydrogen-ion concentration well on the alkaline side. This is due to its nearly complete hydrolysis in

[6] Foreman, Fred: Hydrothermal Experiments on Solubility and Oxidation of Iron and Copper Sulfides. ECON. GEOL., vol. 24, p. 811, 1929.

water to form sodium hydroxide and sodium hydrosulphide by the following equation:

$$Na_2S + HOH \rightleftharpoons NaOH + NaHS.$$

The solution may be made neutral by treating it with H_2S and converting the NaOH, formed by the equation above, into NaHS. Solutions of Na_2S are prepared by saturating a given volume of sodium hydroxide solution with H_2S, then adding an equal volume of sodium hydroxide of the same strength. Foreman's description of his sulphide solutions as being neutral or alkaline gives but little knowledge of their composition.

The experiments to be described in this paper show that the composition of these sulphide solutions has a decided effect on the products formed. Those sodium sulphide solutions which Foreman describes as neutral must, necessarily, have been solutions of the hydrosulphide, NaHS, possibly with excess H_2S. The writer's experiments indicate that pyrite is stable in sodium hydrosulphide. How alkaline were the solutions which he terms "alkaline"? If they were slightly alkaline no reaction with pyrite would be expected as they would approximate the composition of NaHS. On the other hand, if they were strongly alkaline, they would cause a very decided alteration of the pyrite. By the action of alkali hydroxides on pyrite and marcasite H. N. Stokes [7] was able to convert them to hematite. The reaction is not dependent on the presence of air and is expressed by the equation:

$$8FeS_2 + 30NaOH \rightarrow 4Fe_2O_3 + 14Na_2S + Na_2S_2O_3 + 15H_2O.$$

In many of Foreman's experiments an atmosphere of carbon dioxide was used, but carbon dioxide is not an inert gas and might determine to some extent the products formed. Under certain conditions it acts as an oxidizing agent. It dissolves in water forming carbonic acid, H_2CO_3, a weak acid but one that is able to displace H_2S from its salts. For these reasons the hydrothermal experiments to be described were performed in an atmosphere of nitrogen.

[7] Stokes, H. N.: Experiments on the Action of Various Solutions on Pyrite and Marcasite. ECON. GEOL., vol. 2, p. 14, 1907.

A hint as to the nature of the green solutions of FeS obtained by Becker, Freeman and others is given by the researches of S. M. Horsch.[8] By passing hydrogen sulphide into a mixture of ferric oxide and sodium hydroxide he obtained a red product, which dissolved in water, giving an emerald green solution. The composition of the material dissolved in this solution was $4Na_2S \cdot FeS$. Upon dialysis a gel was obtained, having the composition $Na_2S \cdot 2FeS$, and this dissolved in water to give a dark solution. By adding sodium sulphide slowly the green color was found to reappear when the composition corresponded to $4Na_2S \cdot FeS$. Colloidal solutions of ferrous sulphide are frequently mentioned in the literature, particularly in regard to their pharmacological uses. Evidently the solution of ferrous sulphide obtained by Freeman was a lyophile colloid, *i.e.*, a colloidal solution which shows a marked combining power between the solid and liquid phases.

The experiments described in this paper show that pyrite is attacked by Na_2S solution with the formation of pyrrhotite and alkali polysulphide. A small quantity of the ferrous sulphide formed is retained by the solution as a colloid and causes the solution to be deep green in color. This alteration of pyrite to pyrrhotite, whether or not common in nature, leads to important generalizations concerning the formation of pyrite and of pyrrhotite in alkaline solutions.

Syntheses of pyrrhotite which have application in nature are not numerous. By heating artificial magnetite to whiteness in hydrogen sulphide, M. Sidot [9] obtained hexagonal crystals having the composition of FeS. R. Lorenz [10] heated iron to whiteness in hydrogen sulphide and obtained troilite, and C. Doelter [11] obtained troilite from $FeCO_3$ or $FeSO_4$ in H_2S at white heat. E.

[8] Horsch, S. M.: Colloidal Double Sulphide of Iron and Sodium. Bull. Soc. Chim. de France, vol. 27, p. 777, 1920.

[9] Sidot, M.: Sur la préperation des sulfures de fer et de manganese. Compt. Rend., vol. 66, p. 1257, 1868.

[10] Lorenz, R.: Mineralsynthetische Versuche. Ber. Deutsch. Chem. Gesell., vol. 24, p. 1504, 1891.

[11] Doelter, C.: Ueber die künstliche Darstellung einiger Mineralien. Zeitschr. Kryst. Min., vol. 11, p. 29, 1886.

T. Allen [12] and his colleagues have prepared pyrrhotite from pyrite by dissociation at temperatures above 550° C. According to them pyrrhotite exists in two modifications, hexagonal below 138° C. and orthorhombic above 138° C. They regard troilite not as a separate mineral but as a limiting composition of the mineral pyrrhotite.

In the same investigation Allen and his co-workers prepared pyrrhotite from a weakly acid solution of ferrous salt by means of hydrogen sulphide, and they give a detailed description of its crystal form. C. Doelter [13] made pyrrhotite by heating a solution containing ferrous chloride, sodium carbonate and hydrogen sulphide at 200° C. for sixteen days in the absence of air. When air was admitted pyrite was formed instead. The action of air in this case is an interesting effect which will be considered later.

THE ACTION OF SODIUM SULPHIDE ON PYRRHOTITE.

Experiments were made to prepare green solutions of ferrous sulphide, such as those previously described by Freeman, and to determine their properties and nature. The pyrrhotite used was the natural variety, examined optically, and selected for purity.

The pyrrhotite was crushed to coarse grains in an agate mortar and immediately transferred to a pyrex flask containing 40 milliliters of 0.2 normal sodium hydroxide, free from carbonate, and hydrogen sulphide was passed through for some time while the solution was watched and all changes noted. Gradually the solution took on a deep green color, then as hydrogen sulphide continued to pass, it slowly became dark brown. The hydrogen sulphide was then turned off and nitrogen bubbled through for some time, after which the green color again appeared. This green solution was then brought to boiling and again turned brown. This simple experiment could be repeated at will. Thus sodium sulphide was seen to have a solvent action on the pyrrhotite, the resulting solution turning from green to brown on the addition of hydrogen sulphide or on boiling.

[12] Allen, E. T., Crenshaw, J. L., and Johnston, J.: The Mineral Sulphides of Iron. Am. Jour. Sci., (4) vol. 33, p. 170, 1912.

[13] *Op. cit.*

It was desired to find the quantity of ferrous sulphide in solution and to determine the effect of diffusion on the green liquid. Hydrogen sulphide was bubbled for one hour through 100 milliliters of 0.2 normal sodium hydroxide free from carbonate, in a flask containing a gram of crushed pyrrhotite. As before, the solution turned green, then brown, and on loss of hydrogen sulphide by exposure again turned green. In order to determine the concentration of ferrous sulphide, a portion of the solution was filtered through Schleicher and Schüll No. 589 paper to remove any non-colloidal material in suspension, the sulphur oxidized with aqua regia, and the iron precipitated as hydroxide. The iron calculated to ferrous sulphide gave a concentration of 0.055 gram of FeS per liter. Although the quantity of ferrous sulphide found was small, the solution was an inky green, of such a deep color that it could be seen through only by holding it toward strong light. Such a depth of color for a dilute solution is itself a strong indication of the presence of a colloid.

A study was made of the diffusion of these green and brown solutions through agar gel. A 3 per cent solution of agar in hot water was poured into test tubes filling them to a depth of about 8 centimeters, and the gel allowed to set. The solutions being studied were poured over this gel and the tubes tightly stoppered. Diffusion of the solution through the gel was measured from time to time and a comparison made with the diffusion of a copper sulphate solution. The results are given in Table I. The experiment showed that the ferrous sulphide solutions do not diffuse readily through a gel and that in this respect they resemble colloidal solutions.

TABLE I.

DIFFUSION OF COLLOIDAL FeS THROUGH AGAR GEL.

Solution.	Day Started.	March 12.	April 12.
Saturated $CuSO_4$.....	March 3	Blue throughout	
Green FeS solution.....	do.	Green diffused to about ½ cm.	No change
Brown FeS solution (excess H_2S).....	do.	Black to about 1½ cm.	No change

Another indication of its colloidal nature was obtained by passing an electric current through the solution, for the green color could not be made to migrate from one electrode to the other through a semi-permeable membrane.

Colloids may be precipitated from solution by means of salt, deltas being formed in this way where rivers enter the sea. This property of electrolytes has received considerable attention in the study of colloidal chemistry. Electrolytes were found to have such an effect on the green solution prepared from pyrrhotite, causing the green color to precipitate and the solution to become perfectly clear. A quantity of the deep green solution containing 0.055 gram FeS per liter was made in the usual manner from pyrrhotite, and 25 milliliter portions placed in small bottles and tightly stoppered. Weighed quantities of different electrolytes were then added, 0.01 gram each day until precipitation was complete (Table II).

TABLE II.

PRECIPITATION OF COLLOIDAL FeS BY ELECTROLYTES.

Electrolyte.	Wt. Required in Grams for 25 Ml.	Concentration Required (Milli-mols per Liter).
$BaCl_2.2H_2O$	0.01	1.6
$(NH_4)_2C_2O_4.H_2O$	0.02	5.6
NH_4Cl	0.02	15.
$NaCl$	0.03	21.
$Na_2B_4O_7.10H_2O$	0.03	3.1
KCl	0.04	21.
KI	0.04	9.6
Na_2CO_3	0.04	15.

Other electrolytes found effective as precipitants were Na_2SO_4, $Na_2S_2O_3$, Na_2SO_3, $MgCl_2$ and $(NH_4)_2CO_3$. The colloid could also be removed from solution merely by cooling considerably below room temperature. A stoppered bottle of the green solution was placed under a tap and cold water run over it for some time. A black precipitate formed in the bottom of the bottle, while the solution above became perfectly clear.

The presence of alkali polysulphide in solution does not prevent the formation of this colloid but seems rather to act as a peptizing agent. The following experiment illustrates this. 100 mil-

liliters of 0.2 normal sodium hydroxide was saturated with hydrogen sulphide and 1.62 grams of crushed pyrrhotite added. Hydrogen sulphide was allowed to flow through the solution for another hour and 20 milliliters was then withdrawn for analysis. It was found to contain 0.05 gram FeS per liter. 1.5 grams of sulphur was then added, an excess over that required to form Na_2S_5 by the following reaction:

$$2NaHS + x\ S \rightarrow Na_2S_{(x+1)} + H_2S.$$

The solution was digested in a stream of hydrogen sulphide until solution of the sulphur was complete, H_2S then turned off, and the solution cooled tightly stoppered. It became a deep inky green. An analysis of a 20 milliliter portion gave 0.11 gram FeS per liter. The solution was then subjected to a stream of hydrogen sulphide for one hour, during which sulphur was copiously precipitated and the solution became deep brown. Analysis of this solution then showed that there was 0.10 gram FeS per liter. The increase of concentration of FeS from 0.05 gram to 0.11 gram per liter was believed due to the peptizing action of polysulphide.

The effect of higher temperatures on the formation of the colloidal solutions could not be determined. Presumably the colloids could be formed at higher temperatures but it is not possible to say whether the quantity formed at the higher temperature would be greater or not. All of the solutions obtained in the bomb at 300° C. by the action of sodium sulphide on pyrite contained the green colloid.

These studies show that pyrrhotite can be dispersed by sulphide solutions, forming a deep green colloidal solution. The solubilities reported by the earlier workers probably refer to colloidal solutions. The true solubility of pyrrhotite in such solutions is considerably smaller, and, so far as known, it is best expressed by the solubility-product relationship ordinarily used in physical chemistry.[14] According to Weigel the solubility of precipitated ferrous sulphide in water is about 0.6 milligrams per

[14] Stieglitz, Julius: Qualitative Analysis, p. 137. Wells, R. C.: The Fractional Precipitation of Ore-forming Compounds. U. S. Geol. Survey Bull. 609. p. 14.

liter [15] and the mass action effect of the sulphide ion would decrease the iron content correspondingly.

Some writers believe that ores may be carried in solution as colloids, later to be deposited in large ore bodies. At the present time any decision on this point seems largely a matter of opinion, as much evidence, both experimental and in the field, is needed before an entirely satisfactory conclusion can be drawn. It is clear that the presence of electrolytes in underground waters would not only prevent solution of ferrous sulphide as a colloid but cause immediate precipitation whenever such solutions were formed. The adsorptive effect of the rocks through which the solutions pass might also lessen such transportation, through the action whereby one colloid may precipitate another.

THE ACTION OF SODIUM SULPHIDE ON PYRITE.

That sodium sulphide solutions would alter pyrite was expected in view of the experiments on the action of alkalies on pyrite by H. N. Stokes.[16] He found both sodium hydroxide and sodium carbonate effective in changing pyrite to hematite, even when all air was excluded from the reaction. Sodium carbonate and sodium sulphide are similar in many respects. Both are salts of a strong base (NaOH) and weak acids (H_2CO_3 and H_2S) and so both would have a strong alkaline reaction. However, of the two acids H_2S is the weaker; the ionization constant for carbonic acid is 3040×10^{-10}, while that for hydrogen sulphide is 13×10^{-10}.[17] For this reason Na_2S would have a more alkaline reaction than Na_2CO_3. As sodium carbonate has been found effective in altering pyrite to hematite, some reaction from the more alkaline salt, sodium sulphide, might be expected.

For the hydrothermal experiments a bomb, such as that described by Allen [18] and his coworkers, was used. It consisted simply of a large steel cylinder and a top which could be con-

[15] Weigel, O.: Zeitschr. physik. Chem., 58, 293, 1907.

[16] *Op. cit.*

[17] Getman, Frederick H.: Outlines of Theoretical Chemistry, p. 433. John Wiley and Sons, New York, 1922.

[18] *Op. cit.*

nected with a soft metal washer. Aluminum washers were found entirely satisfactory, being altered only by crystallization into spongy aluminum. The use of a glass tube, as a container for the reactants, was not favored, for glass is attacked to a great extent at 300° C. by alkaline solutions or even by water alone. Instead was used a platinum test tube of 150 ml. capacity with a tight fitting lid.

For the preparation of the sodium sulphide solutions, carbonate-free sodium hydroxide solutions were used. This hydroxide solution was made by dissolving a known weight of the hydroxide sticks in an equal weight of distilled water, allowing to stand over night with the mouth of the flask covered with tin foil, then decanting and filtering with suction through hardened filter paper. The clear liquid was then diluted to the proper volume in a large flask, coated on the inside with paraffin, using boiled and cooled distilled water. The glass stopper was coated with stopcock grease to exclude air. The solution was measured from the flask with a pipette.

The hydrogen sulphide was made by the action of 1–1 hydrochloric acid on ferrous sulphide and passed through distilled water before use.

A measured volume of the sodium hydroxide solution was then taken with a pipette and converted to the hydrosulphide by saturating with hydrogen sulphide. This yielded a solution with an excess of H_2S over that required for NaHS. It was found necessary to bubble hydrogen sulphide through the hydroxide solution for a long period of time, from one to two hours, before saturation was complete. Experiments with sodium sulphide made from NaHS having a shorter period allowed for saturation, yielded oxide of iron on pyrite, in one case beautiful octahedra of magnetite. The NaHS thus prepared was converted to Na_2S by adding an equal volume of the sodium hydroxide.

Natural pyrite was used for the experiments, well crystallized and free from gangue minerals. It was washed with 1–1 hydrochloric acid and distilled water before use. In a number of the experiments it was crushed to coarse chips in an agate mortar,

followed by a rinse with 1–1 hydrochloric acid and then with distilled water.

An experiment was made to verify the work of Stokes[19] on the action of alkali hydroxides on pyrite.

Experiment 1. Action of sodium hydroxide solution on pyrite.

Charge: Large pyrite crystal, 100 milliliter normal sodium hydroxide; atmosphere of nitrogen. Time: About 15 hrs.; temperature: 200° C.

Results: A coating of hematite was found on the pyrite crystal and on the sides of the platinum tube. The solution was light green in color. It was filtered and oxidized with sodium peroxide, after which the sulphur was determined as $BaSO_4$. The test showed that 0.0145 gram of sulphur had been extracted from the pyrite. A blank test on the sodium hydroxide and sodium peroxide used gave no sulphate.

The changes are expressed in the following equation:

$$8FeS_2 + 30NaOH \rightarrow 4Fe_2O_3 + 14Na_2S + Na_2S_2O_3 + 15H_2O.$$

The following experiment shows that in the formation of pyrite from ferric oxide and sulphur neither hydrogen sulphide nor a solvent, such as sodium carbonate, need be added.

Experiment 2. Formation of pyrite from ferric oxide and sulphur.

Charge: 0.5 g. sulphur, 0.5 g. Fe_2O_3, 50 ml. H_2O, atmosphere of CO_2. Time: 3 days; temperature: 300° C.

Results: The product appeared to be pure pyrite, but it was prepared for analysis by washing with dilute hydrochloric acid and distilled water. It consisted of crystalline material, coarse enough so that its crystalline nature, luster and color could be seen with the naked eye. An analysis gave 48 per cent Fe, 52 per cent S, a composition close to FeS_2.

The next experiment shows the conversion, by Na_2S, of pyrite into pyrrhotite. A more quantitative study of this reaction is given later.

[19] *Op. cit.*

Experiment 3. Action of sodium sulphide on pyrite.

Charge: Crystal of pyrite weighing 8 g., 50 ml. normal Na_2S, atmosphere of nitrogen. Time: 6 days; temperature: 300° C.

Results: The solution was a deep inky green. Small bunches of a pseudocrystalline material had formed on the pyrite, having a bronze color and irridescent luster. It gave all the qualitative chemical tests for pyrrhotite. It adhered to a magnet. Dilute hydrochloric acid decomposed it with the evolution of hydrogen sulphide and the solution of iron.

Experiment 4. Action of sodium hydrosulphide solution on pyrite.

Charge: 4 g. pyrite chips, 50 ml. normal NaHS + excess H_2S, atmosphere of nitrogen. Time: 4 days; temperature: 300° C.

Results: The pyrite remained unaltered, showing that it is perfectly stable in NaHS solutions under the conditions of the experiment.

In this way it was found that in sodium sulphide solutions pyrite could be altered to a product resembling pyrrhotite in every respect, and when sodium hydrosulphide was used no alteration occurred. These experiments seem to have direct bearing on the absence of reaction found by Foreman [20] in his study of the action of alkali sulphides on pyrite.

The solution obtained in the reaction between pyrite and sodium sulphide in the experiment above was not analyzed, and only a guess can be made as to the mechanism of the reaction. Free sulphur is slowly dissolved by sodium sulphide solutions with the formation of polysulphide. In the reaction between pyrite and sodium sulphide, pyrite may have acted as a potential source of sulphur, part of which was removed by Na_2S to form polysulphide, Na_2S_x, and pyrrhotite. Further experiments were made in order to determine the mechanism of the reaction and if possible to obtain perfect crystals of pyrrhotite. The solutions were analyzed by the A. O. A. C. methods for lime-sulphur solutions.

Experiment 5. Action of sodium sulphide on pyrite.

[20] *Op. cit.*

Charge: 24 g. pyrite chips, 10 g. fused Na_2S (commercial), 75 ml. H_2O, atmosphere of nitrogen. Time: 13 days; temperature: 300° C.

Results: The solution was deep brown in color, turning to green on loss of hydrogen sulphide. It was filtered and analyzed as quickly as possible to prevent decomposition. In this analysis only the ratio of monosulphide sulphur to total sulphide sulphur was determined. The solution was made to 200 milliliter volume and a 10 milliliter aliquot titrated with standard iodine. This titration gave 0.1055 gram sulphur in 10 milliliters as monosulphide sulphur. The monosulphide and polysulphide were then precipitated simultaneously from a 25 milliliter aliquot with ammoniacal zinc chloride, removed by filtration, oxidized with sodium peroxide, and sulphur determined gravimetrically as $BaSO_4$. This yielded 0.1713 gram total sulphide sulphur for 10 milliliters of the solution. From this the value of x in the polysulphide formula, Na_2S_x, is $\frac{0.1713}{0.1055}$ or approximately 1.63.

From the solid product large fragments of pyrrhotite could be removed with a magnet. The use of a magnet was unnecessary, however, for the pyrrhotite could be separated from the pyrite merely by difference in color. A large number of crystal groups were noted, as twinned hexagonal plates of pyrrhotite. One crystal showed a perfect hexagonal face measuring approximately 2 mm. across. A small sample of the less perfect crystals weighing 0.1584 gram was taken for analysis. It was oxidized by fusion with sodium carbonate and sodium nitrate, the iron determined gravimetrically as Fe_2O_3, the sulphur as $BaSO_4$. The result of the analysis was: Fe, 63.5 per cent.; S, 37.0 per cent.; total 100.5 per cent. Fe : S = 1.00 : 1.02, or very close to FeS.

Because of the large quantity of impurity in commercial fused sodium sulphide the experiment was repeated using a normal solution made from carbonate-free sodium hydroxide with hydrogen sulphide. This necessarily contained an excess of hydrogen sulphide and so was expected to form less polysulphide sulphur by action on pyrite. A much shorter period of time (15 hrs.) was used to see if the reaction took place readily. The resulting

solution was analyzed to account, as far as possible, for all the sulphur in solution.

Experiment 6. Action of sodium sulphide on pyrite.

Charge: 10 g. pyrite chips, 100 ml. normal Na_2S, atmosphere of nitrogen. Time: About 15 hrs.; temperature: 300° C.

Results: The solution contained a large quantity of hydrogen sulphide and effervesced on being turned out of the platinum tube. It was brown but quickly turned to green on exposure and loss of hydrogen sulphide. It was filtered at once through lintless cotton broadcloth and made to a volume of 500 milliliters in a volumetric flask, using boiled and cooled distilled water. The solution was then transferred to small bottles of 25 milliliters capacity, corked and sealed with paraffin, and kept in a dark place until used. Analyses of these solutions were made as quickly as possible and gave the following results per milliliter: 0.0019 milliatom of sulphur as thiosulphate; 0.0851 milliatom of sulphur as monosulphide; 0.1239 milliatom of sulphur as monosulphide plus polysulphide; and 0.1260 milliatom of total sulphur. The value for total sulphur shows that only 0.0002 milliatom of sulphur per milliliter is unaccounted for.

By dividing the figure for monosulphide plus polysulphide by that for monosulphide, $\frac{0.1239}{0.0815}$, the value x for the polysulphide, Na_2S_x, is 1.46. This value is no doubt low due to the effect of H_2S on the monosulphide titration and on the action in the bomb, and it probably approaches the value 2. The ratio, however, shows that polysulphide sulphur is present in large quantity.

The pyrite had formed a cake at the bottom of the tube and the upper part of this mass was largely converted into pyrrhotite. This was well enough crystallized so that an occasional shiny hexagonal face could be seen with the naked eye. Under the microscope many hexagonal plates, bronze and iridescent, could be seen.

Some of the pyrrhotite was removed by means of an electromagnet and the material analyzed. The results were: Fe, 61.5 per cent.; sulphur, 36.3 per cent.

That some indication of the alteration of pyrite to pyrrhotite may be obtained at lower temperatures is shown by the following experiment.

Experiment 7. Action of sodium sulphide on pyrite.

Charge: 5 g. pyrite chips, 100 ml. normal Na_2S, atmosphere of nitrogen. Time: About 15 hrs.; temperature: 96° C.

Results: The pyrite was slightly but definitely altered and showed occasional flakes of a darker mineral. A few magnetic particles were extracted, which showed the characteristic color of pyrrhotite but no well defined crystalline form. These particles decomposed in dilute hydrochloric acid, iron going into solution and hydrogen sulphide being evolved.

The solution was a clear yellow turning to green on exposure to air.

It was considered barely possible that sodium sulphite might act in a similar way as an extractor of sulphur from pyrite, the supposed products being pyrrhotite and sodium thiosulphate by the equation:

$$FeS_2 + Na_2SO_3 \rightarrow Na_2S_2O_3 + FeS.$$

Experiment 8. Action of sodium sulphite on pyrite.

Charge: 2 g. pyrite chips, 50 milliliters normal Na_2SO_3, atmosphere of nitrogen. Time: 4 days; temperature: 300° C.

Results: The solid product was a thin coating of red hematite covering the pyrite fragments and very fine shiny crystals that appeared to be recrystallized pyrite. The product was not attacked by 1–1 hydrochloric acid in the cold; in hot acid the solution turned brown (Fe^{+++}) but gave no test for hydrogen sulphide showing that pyrrhotite was not one of the products formed.

DISCUSSION.

The hydrothermal experiments on pyrite illustrate a manner in which pyrite might alter to pyrrhotite in nature, but the reaction is by no means of universal application. The writer has heard of few instances in which this change might have taken

place. Nevertheless, further consideration of the equilibrium leads to conclusions which are of general application to the formation of pyrite and pyrrhotite and to ore bodies as a class.

The reaction seems best to be expressed as an equilibrium, the final products being dependent on concentrations, pressures, and temperatures. Analysis of the solutions resulting has led to the formula Na_2S_2 as best expressing the polysulphide formed in the reaction. The reaction would then be expressed as follows:

$$FeS_2 + Na_2S \rightleftharpoons Na_2S_2 + FeS.$$

Or, as no strictly quantitative knowledge has been obtained as to the polysulphide formed, the following equation would have more general application:

$$x\ FeS_2 + Na_2S \rightleftharpoons Na_2S_{(x+1)} + x\ FeS.$$

The ferrous sulphide thus formed is dissolved to a very slight degree forming a colloidal solution. Perhaps owing to this fact the pyrrhotite does not form a coating on the pyrite, as is the case with most mineral alterations, but forms distinct crystals, or disseminated crystal groups about the surface of the pyrite. The colloidal ferrous sulphide could be carried for short distances in solution from the original pyrite, later to be precipitated by electrolytes, change in physical environment, adsorption, or other effects common in the coagulation of colloids.

In contrast to the action of sodium sulphide solutions, brief consideration suffices to show why sodium hydrosulphide caused no alteration of pyrite to pyrrhotite. Sulphur may be dissolved in hydrosulphide forming polysulphide and hydrogen sulphide:

$$2NaHS + x\ S \rightleftharpoons Na_2S_{x+1} + H_2S.$$

The gaseous product of this reaction, H_2S, imposes limiting conditions and the reaction may be made to proceed to the right or to the left. From hot solutions the hydrogen sulphide escapes into the atmosphere and the reaction proceeds to the right. But by passing hydrogen sulphide into cold solutions of alkali polysulphide the reaction may be made to proceed to the left, sulphur

precipitating and the hydrosulphide being formed. Thus where the pressure of hydrogen sulphide is high the hydrosulphide can dissolve but little sulphur. Under hydrothermal conditions where hydrogen sulphide has little chance of escape, its presence would tend to prevent the extraction of sulphur from pyrite by hydrosulphides.

The equilibrium of pyrite with sodium sulphide has broader geochemical application than merely to this alteration, as it is involved in a general way in the formation of pyrite and pyrrhotite from alkali sulphide solutions. In the discussion to follow pyrrhotite will be represented by the simple formula, FeS, although usually an excess of sulphur is present in the natural mineral.

Ferrous sulphide is formed by the reaction between an alkali sulphide and a ferrous salt:

$$FeCl_2 + Na_2S = 2NaCl + FeS.$$

Under hydrothermal conditions ferrous sulphide thus produced is in the crystalline form, pyrrhotite, due to conditions of high temperature and pressure. If the disulphide, Na_2S_2, were substituted for Na_2S in the above reaction there would be an atom of sulphur in excess over that required for FeS, and FeS_2 should be produced instead: $FeCl_2 + Na_2S_2 = 2NaCl + FeS_2$.

As the ratio of polysulphide to monosulphide increases toward the composition Na_2S_2, a larger proportion of sulphur combines with the iron until the limiting composition FeS_2 is attained. With compositions between Na_2S and Na_2S_2 there would be an equilibrium established between pyrrhotite, pyrite, sodium monosulphide, and sodium polysulphide as follows:

$$FeS + Na_2S_2 \rightleftharpoons FeS_2 + Na_2S.$$

Thus the final solid products are chiefly determined by the ratio of monosulphide to polysulphide in the alkali sulphide solution.

The presence of oxidizing agents causes changes in the composition of the sulphide solutions and so determines whether

pyrrhotite, pyrite, or oxides are formed. The first product of oxidation in a solution of sodium sulphide is free sulphur which dissolves in the remaining sulphide to form polysulphide. In the presence of iron salts some of the polysulphide reacts to form pyrite. This primary oxidation may also yield some thiosulphate, from which pyrite has been made by E. T. Allen [21] and his colleagues. Thiosulphate, however, is known to be unstable at high temperatures and pressures. Thus, in the bomb overnight at 300° C. it was found that a solution of thiosulphate decomposed into sulphate, hydrogen sulphide, polysulphide, and free sulphur. In the presence of salts of iron, polysulphide and free sulphur would form FeS_2, as already described. It can be seen that ferric salts would have a similar oxidizing action on the sulphide solutions and in this way would favor the formation of pyrite.

These considerations would probably be applicable to other pairs of sulphide ores, such as those of copper, chalcocite, Cu_2S, and covellite, CuS, though this has not yet been determined.

Concerning the formation of pyrite and pyrrhotite in acid solutions we may again refer to the researches of Allen [22] and his colleagues. Pyrite and marcasite were prepared in solutions containing sulphuric acid, the more acid solutions favoring the formation of marcasite. Pyrrhotite was formed in slightly acid solutions of ferrous salts by means of hydrogen sulphide. Owing to the presence of some ferric salt a little pyrite was formed at the same time.

The effect of oxidizing agents in these acid solutions is similar to that in alkali sulphide solutions, their presence favoring the formation of pyrite or marcasite. The oxidation of hydrogen sulphide is given by two equations:

$$(1) \quad 2H_2S + O_2 = 2H_2O + 2S,$$
$$(2) \quad 2H_2S + 3O_2 = 2H_2O + 2SO_2.$$

In a limited supply of oxygen, sulphur is set free in accordance with reaction (1) and, as shown, free sulphur reacts to form pyrite or marcasite when iron salts are present.

[21] *Op. cit.*
[22] *Op. cit.*

The formation of pyrrhotite in acid solutions would apparently be dependent on the reversibility of the reaction:

$$FeS + 2HCl \rightleftharpoons FeCl_2 + H_2S.$$

Under surface conditions the reaction goes to the right and is used in the preparation of hydrogen sulphide. The reaction is a reversible one, however, and under conditions of high pressure pyrrhotite might be stable even in acid solutions.[23]

These principles define the conditions under which pyrrhotite, pyrite and marcasite are formed in solution. They are summarized briefly in the following conclusions: (1) Pyrrhotite can be dispersed to a small extent in sodium sulphide and polysulphide solutions, giving a deep green colloidal solution. (2) Pyrite is attacked by solutions of sodium sulphide, Na_2S, forming pyrrhotite and sodium polysulphide. (3) Pyrrhotite is formed when hydrogen sulphide, alkali sulphides, or alkali sulphide solutions weak in polysulphide react with ferrous salts under hydrothermal conditions. (4) FeS_2 is formed from iron compounds in alkaline solutions containing a high ratio of polysulphide to monosulphide, or in the presence of free sulphur or a compound capable of liberating free sulphur by decomposition.

The advice of Dr. R. C. Wells, Chief Chemist, U. S. Geological Survey, has been of great value in this study and his guidance is gratefully acknowledged.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

[23] See Friend, J. N.: Textbook of Inorganic Chemistry, vol. IX, part II, p. 134. Griffin & Co., Ltd., London, 1921.

ECONOMIC GEOLOGY AND ITS ALLIED SCIENCES IN ANCIENT TIMES.[1]

CORNELIO L. SAGUI.

ANCIENT LITERATURE

Scientific Thought in Ancient Literature.—As very little is known of the economic geology of early civilizations, a brief preliminary summary of the references to the physical sciences found in ancient literature may enable the reader to appreciate at their true value the observations made by the writer in the ancient mining districts along the shores of the Mediterranean.

For such information three sources are available—(1) the Ionic School of Literature, (2) the Athenian Literary School, and (3) the popular literature.

1. The Ionic School, which is represented by such well known names as Democritus, Heraclitus, Pythagoras, Hipparchus, Thales, and Epicurus, furnishes the best scientific thought. The fragments of their doctrines that have survived show how high was the standard of this famous school.

2. The writings of the Athenian School, of which Plato is a notable example, consist largely of philosophical works, and little attention is given to the experimental sciences.

3. To the third class belong the superstitions, popular errors, and legends.

The Athenian School was dominant during the height of Grecian supremacy, and its exponents were exceedingly critical of the Ionian School. The Athenian Plato is said to have been so much prejudiced against the writings of Democritus as to advocate the destruction of his entire scientific writings. Nevertheless, the fundamental thought of Democritus can now be recognized as of great importance. His theory of the Universe, namely, that it is made up of atoms united in the various forms

[1] English revised by E. B. Whittlesey.

of the world of phenomena, may be compared with our modern theory of the electron, or an elementary electromagnetic quantum.

But Democritus went further, and supposed the atoms to originate not only matter but energy. From a purely philosophical point of view he clearly stated the subjective character of our sensations, as well as the invariable relation of cause and effect. He may indeed be considered the father of the Cartesian philosophy as well as of determinism. Furthermore, he had a clear idea of the infinity of interstellar space.

Heraclitus was, if possible, an even more wonderful genius of the Ionic School. He was probably the first to conceive of the Universe as a river of phenomena, incessantly flowing and continually changing. In the field of physics Heraclitus apparently reached conclusions toward which modern thought is now converging. He considered fire the fundamental element of the universe; not the vulgar fire that we know, however, but a subtle and invisible fire—in other words, the electro-magnetic field of our modern physics. "This fire is matter, energy, and life, it is a living fire" (πῦρ αεί ζῶον).

From such high standards it may well be inferred that the geologist must have been well versed in his profession, for although his social rank as a slave did not permit his knowledge to be transmitted in literature, in the limited area of the Grecian Archipelago he could not have failed to get intellectual stimulus from the celebrated philosophers and to acquire a keen sense for the analysis of geological problems.

Historical records of the science, however, are extremely niggardly, and of the fifty and more centuries of mining work done before the Christian era all the information available is less than that referring to one military general, of only mediocre ability. This profound oblivion has been intensified by the modern mining industry, which has destroyed the relics of the past without, as a rule, even noting them.

To trace economic geology back to its origin is impossible, but we may estimate the molding influences of the civilizations that preceded the Grecian. An architectural criterion would seem to indicate that Greek civilization had its main origin in Egypt,

where architecture reached a remarkable development. Nothing could be more impressive than the Egyptian monuments, with their powerful immobility and unchangeableness, with a sense of mystery in ornamental detail that is epitomized in the merciless and inscrutable silence of the Sphinx. But the Grecian temple, if it conserved something of Egyptian solemnity, lost its ominous portentousness and became the expression of a people living in the sun and developing its genial thought in the open.

It is probable that geologists emigrated from the mining districts of Nubia, Meroe, and the vast plains between the Nile and the Red Sea to the milder climate of the Archipelago.[2] Some from Egypt were undoubtedly sold to Greek merchants and thus brought to Greece their geological knowledge, which, like the other Egyptian sciences, was probably occult. But the most important geological and metallurgical lore presumably reached the Aegean Sea through Damascus and other famous industrial districts in Asia Minor. The writer has found in the little-explored regions of Asia Minor old mine workings in great abundance; it would be of interest if the Turkish Government, in years to come, would gather all possible information regarding some of these mining districts which are still practically intact.

AGE OF THE ANCIENT MINES.

This is difficult to establish. In a preceding study,[3] the age of the mines at Cassandra was estimated. We know that under Pericles' rule [4] about twenty thousand slaves were working at Laurium, but a historical consideration of the irregular and periodic development of the mines makes it probable that the population of that district throughout its mining activity averaged about 5000. Taking into consideration the families of the workers, the carriers, etc., we may limit the number of workers directly engaged in extracting ore to about 150. At Laurium the whole underground work included about 2000 shafts and 140

[2] Strabo XVII, p. 82. Diodorus I, p. 33.

[3] Sagui, C. L.: The Ancient Mining Works of Cassandra, Greece. ECON. GEOL., vol. 23, No. 6, pp. 671–680.

[4] Ardaillon: Laurium, pp. 98–101.

kilometers of tunnels and stopes. Though there is no evidence as to the rate of excavation, it may be assumed that the average would be not more than the equivalent of one shaft per year, and a conservative estimate of the length of time required, based on the size of the shafts and an estimated working force of 150 men, would indicate about twenty centuries of work.

The old shafts at Laurium have, as a rule, a section of 2.6 square meters, or in the rectangular shafts 1.3 x 2 meters, and only two miners could work together on such a small surface.[5]

If we consider that Laurium in the time of Pericles was probably a much more extensive district than now, and that the old stopes are computed here as sections of a shaft, which was not the case, this twenty centuries might reasonably be lengthened to thirty, or approximately the same as the age of Cassandra as estimated by the writer. The mines of Asia Minor and Egypt are undoubtedly much older, although direct evidence is lacking.

In the case of the ancient Etruscans, however, whose mines in the Apuane Alps were carefully examined by the writer, more data are available. A fact that immediately impresses the observer is the similarity of their mining methods with those of Asia Minor and Cassandra, which supports the current belief that the Etruscans belonged to the same race as the Trojans and that in common with the Greeks they emigrated fifty centuries ago from Asia Minor.

The Etruscan tunnels which were visited by the writer give a painful sense of suffocation, though the air penetrates them freely, on account of their narrowness. The Romans used cynically to designate the slaves who spent their lives in hard labor in such prisons as *instrumenta vocalia.* It is impossible to visit these mines without contrasting the pitiable lives of the workers with the imposing monuments of marble, silver and gold which were the product of those proud ancient civilizations.

The mines at Bottino and at Argentiera, near by, are still in good condition and afford some interesting details. Argentiera seems to be the oldest mine of the district; its rough egg-shaped

[5] A day's shift, in limestone ore of average hardness, must have been about one centimeter, thus requiring 73 years to excavate one shaft.

tunnels are less cleverly constructed than those at Bottino. It might be stated here that the egg-shaped cross-section was not used because it is the most effective and enduring constructive form, but for the simple reason that it affords a smaller cutting surface. At Argentiera extensive work was done, and dewatering tunnels probably more than 3000 feet in length were dug at different levels. When we consider that the country rocks, crystalline schists of Triassic age, are very hard, and that only one miner could work at a time, it may be assumed that about three centuries were necessary to dig one tunnel only. A conservative calculation indicates that all this work was done in about 23 centuries. The tunnels were well engineered and had a regular outward inclination of one per cent.

These data are not by themselves sufficient to establish the mining age of the district, but in the Bottino mines, evidently later than those at Argentiera, the writer found carved on the rock some Etruscan characters [6] which must pre-date the Roman conquest, about 50 B.C. The Romans, through jealousy, destroyed as far as possible what might remind them of Etruscan superiority, including inscriptions. We may therefore deduce that at least 27 centuries B.C. is a reasonable mining age for this district, and a rudimentary industry probably existed before that time. This estimate seems to be considerably at variance with the historical standpoint. The *sæculum* (century) was an Etruscan unit of time, and they believed their race would endure for ten centuries. Augustus Caesar wrote that the comet of the year 44 B.C. was the beginning of the last century of Etruscan history as an independent people, and that prediction seems to have been correct. However, it is an interesting fact that Egyptologists have found in the literature referring to the wars of Rameses III, the 13th century B.C., precise allusions to an Etruscan fleet.

Another important Etruscan mining district which was described by Simonin [7] some seventy years ago has also been examined by the writer. It is located near Campiglia, Grosseto, Italy. Two huge dikes of extremely hard amphibole, generally

[6] Sagui, C. L.: Mem. Soc. Lunigianese, II, No. 4, G. Capellini, 1921.

[7] Simonin: Ann. des Mines, p. 582, 1858.

poor in metals, were nevertheless mined for copper. They are 120 to 150 feet wide, with marble hanging and footwalls. They were worked at Mount Calvi for a length of about four miles. A large quantity of barren material extracted from the mines is still visible, and seventy years ago the slags then in existence in the Campiglia district were calculated by Simonin at about 100,000 tons.

The writer concludes that these workings are older than those of Argentiera, not only because they were more readily accessible but because of the enormous quantity of work done in excessively hard rock.

In view of the researches carried on by G. Chesneau,[8] the dates mentioned above may well be considered as belonging to a relatively recent period of mining activity. M. Chesneau informs me that many geographical names in central France were derived from ancient gold mines, *e.g. Ariege*—"a river carrying gold." This gold was obtained from quartz veins in which a small amount of arsenopyrite was present. The outcrops were richer than the deposits in depth. Chesneau calculates that these mines were worked more than 10 centuries B.C. His study of ancient Gallic tools, however, takes us back to a mining age of more than 40 centuries B.C. In his paper[9] M. Chesneau is more conservative and presumes that the oldest bronzes of France may be as old as those of the 12th Egyptian dynasty, since they are of the same chemical composition.[10] New archeological discoveries since this paper was written may have altered its conclusions. In fact, archeologists have only recently ventured to look beyond Greek and Roman times. In 1751, the "Académie des Inscriptions" discussed whether the prehistoric battle-axes were used by the knights of the Middle Ages, and in 1817 Grivaud de la Vincelle[11] thought such battle-axes were tools used by the Romans in re-

[8] Directeur, Ecole Nationale superieure de Mines, Paris.

[9] Chauvet, G. and Chesneau, G.: Classification des haches en bronze de la Charente. Congrés de Grenoble de l'Association française pour l'Avanc. des Scien. 1904.

[10] Reinach, Salomon: L'Anthropologie, p. 107, 1891. After the works of A. Wiedemann on the Egyptian bronzes.

[11] De la Vincelle, Grivaud: Recueil de Monuments antiques, vol. II, p. 62.

ligious sacrifices. Bertrand [12] and Fillon [13] supposed them to belong to Caesar's time.

It has been proven, however, that the bronzes of Mount Sinai are similar in composition to the oldest of France, and that copper was known before the first Egyptian dynasty, which according to some authorities ruled fifty centuries B.C. The oldest bronzes were alloys of copper with 3 per cent. arsenic,[14] the latter being added to harden the alloy. In a second period, which Chesneau supposes to have begun some twenty centuries B.C., when metallurgy was well developed, the bronze was of copper with 7 to 12 per cent. of tin; a third period is represented by an alloy of copper, tin (7 to 9 per cent.) and lead (about 6 per cent.). This lead bronze was very brittle, and in order to render it malleable it was re-heated and hammered, as shown by Chesneau's micrographical study.

MINE OWNERSHIP.

A few words may be said here regarding mining legislation in Athens. Aristotle [15] informs us that in Attica the mines belonged to the State and were leased, but as Athens owned only a limited mining zone, outside these limits the mining works may have been individual property. Hyperides [16] mentions that Epicrates was denounced for trespass and the court at Athens acquitted the defendant on the ground that the charge was unfounded. This reference, however, does not in the writer's opinion prove private ownership, since leased land is legally the temporary property of the lease-holder. Smelting and ore-dressing plants, on the contrary, were privately owned, since Demosthenes [17] mentions the selling of a plant. Outside Attica conditions seem to have been different, and Thucydides [18] was the owner of mines in Thrace.

12 Bertrand, A.: Revue archéologique, vol. II, p. 67, 1861.
13 Fillon, Benjamin: Mem. des Antiquaires de l'ouest, p. 10, 1845.
14 Chauvet and Chesneau, *op. cit.*
15 Aristotle: Athen. Resp.
16 Pro Euxen. Col. XLIV and XLV, Ed. Blass.
17 Demosthenes XXXVII, 22.
18 Thucydides IV, 150.

THE BRONZE, COPPER, AND IRON AGES

Literary references would seem to prove that bronze was the most ancient of the metals. But these writers were far away from the origin of metals, and they were literary rather than technical. From a technical point of view the writer believes that bronze is younger than iron and copper and that the latter are practically of the same age. Bronze is a complex metallurgical product and must have succeeded simpler smelting processes. Copper, on account of its bright color, may have been preferred for domestic purposes and for weapons. But agricultural tools, we are informed by the earliest sources, were of iron.[19] Homer mentions in the Odyssey[20] the use of iron for weapons, and Lucretius[21] gives its properties in the following verse:

> Et prior aeris erat quam ferri cognitus usus,
> Quo facilis magis est natura et copia major,
> Inde minutatim processit ferreus ensis.

In the ancient texts, however, it is not always easy to distinguish copper from other metals; the words χαλκέυς, χαλκεῖον, and others were derived from χαλκος (copper) but employed to designate any kind of metal. Miners' tools were made of iron in the most remote ages; rarely were copper tools found in the old workings. The only exception known to the writer is the Gerafalco mine in Tuscany, and the copper tools found there[22] were not cutting tools. It may be concluded that even to mine copper ore iron tools were necessary.

Schliemann[23] has found such domestic tools as keys and knives in Mycene, and though he supposes them to be of the fifth century B.C., it is interesting to note the occurrence of iron utensils in Grecian homes when we consider how little this metal was in favor among our forefathers.

In Egypt iron was used from remote antiquity, probably 30 centuries B.C. Fragments of iron tools were found between the

19 Proclus: Commentary on Hesiodus: Op. et Dies, 150.
20 Homer: Odyss. XVI, 294; XIX, 13.
21 Lucretius: V, 1285.
22 Teodoro Haupt: Resoconto del mio Ser. Min. in Italia. Florence, 1889.
23 Schliemann, Carl: Ausgrab in Troja, Tyrius, Mykenae. 2d ed., Leipzig, 1891.

stones of the Cheops pyramid, and between those of the Karnak Sphinx a small iron scythe was found.[24] When Thothmes III conquered Damascus, which was a famous metallurgical center, in 1590 B.C., his booty was represented by a large quantity of iron.

Moses [25] (1500–1800 B.C.) informs us that in Palestine iron stones were found in great abundance. Ezekiel [26] (Sixth Century B.C.) speaks of Tyre as a great producer of iron. An important discovery consisting of 160,000 kilograms of iron was made by Place [27] at Khorsabad. The industry was evidently flourishing in Phoenicia nine centuries B.C. The Phoenicians were skilful miners and smelters, and their influence extended throughout the Mediterranean coasts, but especially in the islands near their shores. A Phoenician inscription was found in Cyprus [28] in which a smelter is mentioned. Pausanias [29] noted that Theodore of Samos had found a process for melting iron.

Aristotle [30] speaks of molten iron; so also does Pliny [31] (*aquae modo liquari ferrum*). All this proves that cast iron was not unknown to these smelters. The writer has examined iron fragments found in old slags which seem to be cast iron.

In Italy, though the country may not have been rich in ores, iron was mined and smelted long before Rome was founded. Iron objects were found in an old Etruscan tomb at Villanova,[32] and the writer has observed that rich lodes of hematite were mined at Strettoia, Montornato, Fornovolasco, and Montarsiccio, as well as in the well known district of Elba, where magnetite especially was mined. Pliny mentions magnetite [33] and says that the Romans protected their iron objects with white lead, gypsum, and pitch,[34] which implies a certain knowledge of chemistry. Some

24 Reinach, S.: Rev. Arch. 1886.
25 Deuteronomy VIII,
26 Idem, XXVII, 12.
27 Place: Ninive t. I, pp. 83–89, &c.
28 Corpus inser. sem. I, No. 67.
29 Pausanias: III, 12–10.
30 Aristotle: Meteor, IV, 6, 383.
31 Pliny: XXXIV, 146.
32 Gozzani: Un Sepolcreto Etrusco presso Bologna. 1855.
33 Pliny: XXXIV, 147; XXXVI, 126.
34 Idem, XXXIV, 43.

iron mines in the Apuane Alps are apparently as old as the lead and silver mines of the same district, therefore the iron age in Italy, if not the older, is at least very ancient.

Dioscorides [35] speaks of magnetite as lodestone, not as iron ore, and there is reason to believe that the ancients knew and utilized the peculiar properties of lodestone. The Grecian islands were undoubtedly the birthplace of many unrecorded inventions. For instance, Herodotus [36] and other writers mention that Glaucos of Chios devised a way to solder and harden iron. It was here that the writer came across fragments of cast iron. The lodes here were near lignite, indicating the use of metallurgy similar to modern practice, since lignite was also mined.

GEOLOGY APPLIED BY THE ANCIENTS.

In the Apuane Alps, a well defined contact between Triassic crystalline schist and limestone forms an important and recognized horizon where some iron lodes have been found. At Montarsiccio, for instance, the iron ores are represented by pyrite, forming iron oxides near the surface. The ancient miners did not use the pyrite and left it intact as far as possible. It appears, however, that they recognized the pyrite as another form of the surface oxides, and the writer found a short tunnel where work had been immediately discontinued when pyrite was reached, and another tunnel higher up opened where the oxides were found and mined. Apparently no indication of iron ore existed at the surface near the second tunnel. They probably followed veinlets of iron oxide until they struck pyrite, when they rightly judged that the oxides were somewhat nearer the surface.

At Fornovolasco are a number of small ancient workings, roughly horizontal, in correspondence with the contact between schists and limestone. On entering these stopes, one is surprised to find the walls formed of solid iron ore, suggesting at once the existence of a vast iron lode which some recent geologists had calculated to contain a million or more tons of available iron ore.

[35] Dioscorides: V, 147.
[36] Herodotus: I, 25.

I realized, however, from many observations of ancient mines in the Mediterranean countries, that the skill of the ancient miners should not be underestimated. Consequently, my curiosity was aroused by the unusual irregularity of the stopes, which were crooked and in places very narrow, swelling at some points and narrowing at others. On breaking through the iron walls at different places, it was a surprise to discover that only from five to ten inches of ore covered the limestone, and that the quality of the iron ore of the walls was inferior. The ancient geologists knew exactly where to stop digging.

Another instance proving the same point was told me by Mr. G. Fusina.[37] In an old mining field in southwest Sardinia many ancient workings exist, and a modern mining company had driven three long tunnels under the water level where a vein of silver and galena was supposed to be intact. They also erected an expensive ore-dressing plant, houses and offices. In digging foundations for the latter, they encountered a complicated piping system of lead of good quality. The mining staff, rejoicing over this important discovery, commenced to jibe at the ancient miners, who had so kindly left not only a large quantity of ore in the mine but also valuable lead outside. The joke lasted until one day the tunnels reached the vein and met the ancient works, when the joke and also the mining project were abruptly ended.

As has been mentioned, the mines of Bottino are not as old as those of Argentiera, probably because the latter are situated on the side of an easily accessible mountain, whereas the vein of the former outcrops in a rocky and difficultly reached place; above the outcrop rises a vertical cliff, and below, the ground descends steeply. The economic geologists of the Etruscan age must have been aware that the cliff *A' B* (Fig. 1) was formed by a slip along the bedding *MBD*. Thus, when the Argentiera vein approached exhaustion and the geologists were forced to prospect for more ore, the writer believes that only geological knowledge could have guided them to the practically inaccessible outcrop of the Bottino vein.

[37] Official of the technical staff at the Pertusola Mines, Sardinia. Personal communication.

Another splendid example of ancient geological work was observed by Mr. Fusina. At Suzurfuro, Sardinia, a huge lode of galena and blende was worked, but only that part of the lode was chosen where galena was isolated in small lenses, as shown in Fig. 2. The country rock *A* is more porous than *B*, and the concentrations of galena were found just on the contact between *A* and *B*. A correct understanding of the case was evidenced by cross-cutting directly through the unminable lode *M* to the galena lens *G*.

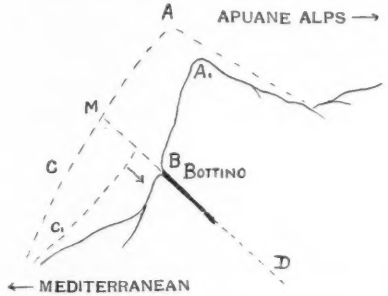


FIG. 1

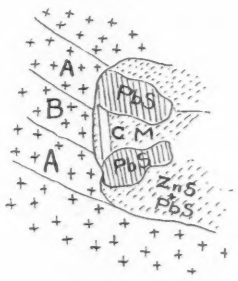


FIG. 2

FIG. 1. Cross-section of Argentiera district.
FIG. 2. Suzurfuro district, Sardinia.

Another instance, where the writer observed the skill of ancient miners, occurs at Papaslik (Gargaron), Adramiti, Turkey, where the lode follows roughly the schist-limestone contact. In places, however, the lode cuts the contact where richer ore occurred. The lode was mined for gold, which was very irregularly distributed, varying in richness from one to 500 grams per ton. The prospecting done by the writer shows invariably that the ancient miners took only the rich parts of the lode, leaving the rest to us. Worthy of note also is the fact that the richest lenses were not discovered haphazard, but by methodical prospecting, in order to reduce to a minimum the workings in barren rock.

It is interesting to compare the characteristics of the mining done in the various Mediterranean countries and to note how similar they are in certain regions and how different in others. For instance, in the region extending from the northern part of

Asia Minor through Thrace, Macedon, and Greece to central Italy, mining methods were practically the same. The shafts were about 1.3 x 2.0 meters in cross-section; they were vertical and regular. The best models have been found at Laurium. Also, the type of ore-dressing plant found at Laurium was used in Thrace, Macedon, Greece and Italy.[38]

Through southern Asia Minor, North Africa, and Spain, however, the mining shafts were smaller and less regular. In Spain they were circular and about one meter in diameter; in Sardinia they were also small. The ore dressing systems, as far as the writer is informed, are also different from those found in the region first mentioned. It would appear that the mining industry emigrated from Asia Minor westward in two separate currents.

MINING PHILOLOGY.

In order to trace the common origin of the Greeks and Etruscans from a mining viewpoint, a few words may be cited that seem to have passed from the Greek language to Latin and Italian dialects through the Etruscan. The most important of these seems to me to be *lizzatori,*[39] signifying the laborers bringing down the blocks of marble from the quarries in Carrara, an ancient Etruscan province. This word is a local one not belonging to the Italian language, but certainly is Etruscan, since the quarries were worked by them and the work has continued without break since those ancient days, nor has the system of transportation from the quarries changed, hence the name for the laborers has persisted. The Greek term for such workers, λιθαγογοί, was evidently corrupted into *lizzatori,* which seems to the writer an important indication that the Etruscan language had much in common with the Greek, notwithstanding the contention of some modern scholars that it belongs, not to the Greek and Latin family, but to the Semitic group.

Another word which seems to have passed from Greek into Latin through Etruria is μάγνις (magnetite), since in Italy the

[38] Sagui, C. L.: Economic Geology and Allied Sciences in Ancient Times. ECON. GEOL., vol. 25, pp. 65–86, 1930.

[39] Sagui, C. L.: Idem.

only important mines of this ore were Etruscan (Elba island). Περίοδος (period) seems to have been a Greco-Etruscan word whose original meaning was the basket or bag used by miners in bringing ore out of the mines. And since this represented short and continuous journeys to and fro, it came to denote any length of time required for a series of operations. The word *palla* (ball) may also have been Etruscan, from the Greek πάλαι (gold nugget). The old High German *ballo, pallo,* may have the same origin.

Σκωρία (slag), ὦχρα, (ochre), κινάβαρι (cinnabar), and other mining terms probably reached Rome through the same Etruscan channel, and it is interesting to note in this connection that Mont Amiata, in the heart of Etruria, is an important producer of cinnabar.

Dewatering wheels were called *tympani* by the Romans, probably an Etruscan adaptation of the corresponding Greek word, though in Greece another term, κοχλία, was used in this connection. The pillars left in the stopes were called ὄρμοι, to which origin it seems logical to refer the Italian word *ormeggiare,* to anchor a ship.

The Italian word *rame* (copper) seems to be Etruscan, but not of Grecian origin. An ancient alloy of copper and zinc called *aeramen,* whose radical *aeris* signifies copper in Latin, seems to indicate the commingling of the Etruscan and Latin in the use of metallurgical terms.

It must be recalled that Etruria was the only important copper producer in Italy, and the copper age of Italy corresponds to the Etruscan. Fornovolasco, an iron-ore district already mentioned, apparently derives its name from the Latin *fornus* and *Volsco* (a people of Latium conquered by the Romans in 338 B.C.)—a hint that the iron industry did not come from Etruria southward but from Egypt by way of Asia Minor. Mont Amiata (*mons,* mountain, *amos,* strong) famous for cinnabar, has a commanding situation far above the surrounding country. On this mountain, on the crest of an anticlinal fold, is situated the town of Arcidosso (*arci,* made, and *dosso,* back). *Dosso* even now signifies back in the Tuscan dialect. Also in the Mont Amiata zone is the

Montieri district, a very ancient mining field, for which the derivation *mons* (mountain) and *ri* or *ril* (old), or possibly *mons* and *aeris* (copper), both of Etruscan origin, has been given.

The Bottino valley, already mentioned, is a deep canyon containing the Vezza River, where for months in winter the sun does not appear; for this reason, no doubt, a town was built by the officials of this Etruscan mining field at the head of the valley several miles from the workings, where the sunlight is more generous. This town (Ruosina) still exists. While the officials found a convenient abode in Ruosina, the laborers had to live in a poor village called Galena, still in existence, built near the workings on a desolate mountain side, where sunlight is brief, though in the heart of sunny Italy. Galena (Etruscan, *gale*, lead), now means lead ore. The Latin name, "lead's village," has survived as the name of the mineral.

FURNACES USED BY ANCIENT SMELTERS.

Smelting in ancient times has already been considered by the writer,[40] but some details may be added here.

Hematite, magnetite, limonite, and siderite were the principal ores of iron mined in ancient times, and we have already noted the importance of the industry in the Near East. In Italy, iron ores were mined principally at Elba and on a smaller scale in other districts, as in the Apuane Alps. In Sardinia iron ores were smelted, and in Spain were the famous mines of Bilbao (Cantabria) mentioned by Pliny.[41] Carinthia was also an extensive iron district, and among the most important mines known are Hüttenberg, Eisenberg, and Vordenberg, where the Romans mined manganiferous siderite with 40 per cent. iron, which became 50 per cent. after roasting.

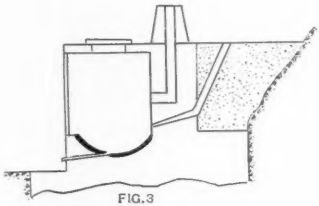
Hematite with a tenor of about 50 per cent. iron was mined at Elba and at Campiglia, on the nearby Etruscan shore. At Monte Valerio, a siliceous iron ore, with 60 to 65 per cent. iron, was mined in order to mix it with that from Elba, which had a

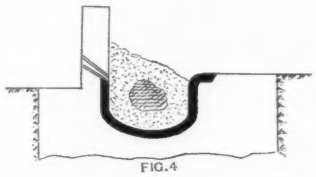
[40] Idem.

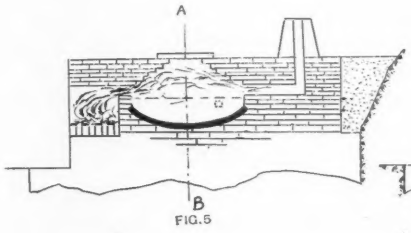
[41] Pliny: XXXIV, 149.

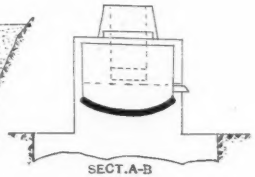
clayey and calcareous gangue. It appears from this that the Etruscans attained some skill in smelting.

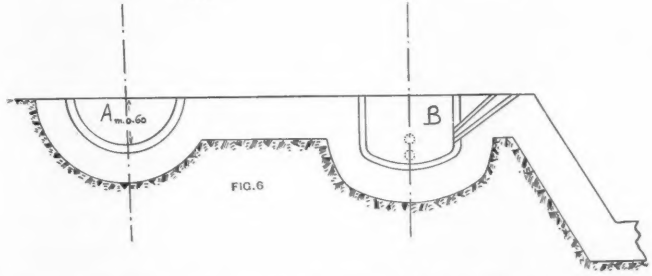
Populonia, near Grosseto, one of the most important metallurgical Etruscan towns, contributed a great quantity of iron to Scipio with which to conquer Carthage, which was finally accom-











FIGS. 3–6. Reconstruction of ancient smelting furnaces by means of fragments found in the old workings. **3.** Cassandra, furnace for smelting argentiferous galena. **4.** Catalan furnace. **5.** Reverberatory furnace. From fragments found at Papaslik (ancient Gargaron) Asia Minor. **6.** From remnants found at Hüttenberg. Siderite was the ore smelted here.

plished with Roman thoroughness. The same destiny, however, awaited the Etruscan provinces, and little by little the hand of Rome pressed more heavily upon them until they too disappeared forever in the mouth of that frightfully voracious monster, the Roman Empire.

Populonia's metallurgical importance was so great that even her coins bore the emblems of her smelting industry, and the ruins of that once famous town are still encircled by large quantities of slag. Though Populonia must have been destroyed about two hundred years before the time of Strabo (63 B.C.–24 A.D.), there were furnaces still at work there in Sylla's day, according to Rutilius Nomatianus.[42]

As to the smelting furnaces of the ancients, not much can be said. After a study of fragments found in the Near East and elsewhere, and with information gathered from ancient texts, the writer has attempted to reconstruct the principal types of such furnaces (Fig. 3–6). The remnants of a furnace were found[43] at Hüttenberg in 1870, and a reconstruction of the whole plant is shown in Fig. 6. The author believes that each group of furnaces was owned by a single family, who operated the smelting plant, worked the iron into various forms and transported the product to markets sometimes at great distances. The conducting of business enterprises by such primitive industrial clans was a common practice throughout the Middle Ages. The ore mined and smelted at Hüttenberg was siderite, which was roasted (*A*, Fig. 6) and smelted (*B*, Fig. 6). The Roman operations here must have continued through the Middle Ages, for outside the highways of the Empire life was isolated and unchanging. The same was true of the little villages in the Apuane Alps where iron was produced. At Fornovolacso are still visible at the bottom of a dark, narrow valley the ruins of a smithy, in a desolate spot near the village, said to be haunted by the ghosts of ancient smelters.

It may be said in conclusion that the flourishing mining industry of the Etruscans and other ancient races ended in Roman

[42] Rutilius Nomatianus: Itin. I, 361.

[43] Jahrb. d. Ver. von Alterthumsfreude im Rheinlande, LXXIX, p. 244, fig. 2.

times or later, under the oppressive darkness of the Middle Ages. But in the obscure villages of the old mining districts, protected by inaccessible mountains and vast forests, miners as well as farmers built up a new industry, proving that the greatest catastrophes may be followed by the highest progress.

GEOLOGISTS AND GEOMETRICIANS.

Shepherds were the first astronomers, and time was the first factor in their conclusions. Distance was measured only by time in the infancy of the races, and length of travel was estimated in fractions of time. But when man became a miner, the measure of space became a necessity in order to locate his underground works correctly. Thus we may say that the miner was the first geometrician, since geometry signifies primarily the measure of the earth and only secondarily the abstract science of space; starting, like other sciences, with practical facts, it developed afterward along speculative lines, thus resulting in a sort of kaleidoscope, where the fundamental background of facts blends with a constantly changing perspective of theory and speculation.

The origin of geometry is a disputed point, however. Herodotus contends that it originated in Egypt, where it was used to measure the shifting sands along the banks of the Nile. But mining work was in progress long before land limits became a subject of discussion. It is also said that Thales brought geometry from Egypt, but this is doubtful, and few elements of the science would have been likely to come through that channel. One thing is certain—the affinity of the Greeks for geometry. A predominant quality of that wonderful race was a profound and harmonious sense of proportion, which formed the very foundation of its art. It is not surprising, therefore, to find Hippocrates teaching geometry in Athens in the fifth century B.C. and making good money by it. He was the pupil of Oenopides, a famous astronomer who founded a celebrated school at Chios.[44] Pythagoras (532 B.C.) of Samos is also considered one of the most noted geometricians, but it is probable that his theorems on the

[44] Proclus: In Euch. 23.

rectangular triangle were originally the work of geologists, for, as will be shown later, mining surveyors had probably already resolved such problems, an absolute necessity in their underground work. And if mining is actually responsible for the creation of geometry, its origins should be sought in Asia Minor and Egypt. In fact, a mathematical papyrus in the Hermitage Museum at Leningrad, written 18 centuries B.C. and only recently deciphered, seems to prove this. It contains twenty-five problems with their solutions, dealing with algebra, plane geometry, volumes and sections.

In Roman times geometry was already a classical science, and no progress was made except in land-surveying. In this field the Romans were clever and original,[45] proving once more that geometry was not originally a speculative science but a practical one.

Mine Surveying Methods.—Regarding mine surveying, we must depend entirely upon archeological findings for reconstruction of methods. At Mount Pangeon, where fragments of a topographic instrument were found,[46] the writer also picked up a metallic rod, badly rust eaten (Fig. 7). To reconstruct the underground surveying method from this slight clue appeared no easy task. The writer had previously surmised, however, that a thin rope must have been stretched through the works in surveying; therefore the problem was to measure the chords of the stations' angles[47] and the distance between the stations. This being the case, the fragments found might be reconstructed into the simple instrument shown in Fig. 8. Let O (Fig. 8) be the station and RR' two rods of equal length hinged in O. An adjustable rod M would measure the chord of the angle AOR; M, being movable, could also be used in measuring the sides AC and RC. Fig. 9 shows the solution of a similar problem. This theory is supported by Agricola[48] on mediæval underground surveying methods.

[45] Gromatici Veteres. Ed. Lachmann, Berlin, 1848.

[46] Sagui, C. L.: *Opus cit.*, ECON. GEOL., vol. 25, pp. 65–86.

[47] Idem.

[48] Georgii Agricolae: De Re Metallica. Basel, 1561. Transl. by Hoover, H. C. and L. H.: Min. & Sci. Press, San Francisco, 1912.

In the days of Agricola the Latin geological terms were still used, and he mentions among others the following: *vena principalis,* main vein; *vena transversa,* cross-vein; *vena crudarium,* outcrop. He also gives many details regarding dewatering pumps, horse-capstans, and wooden railroads. Pascal is said to have invented the wheelbarrow; it is rather surprising, therefore, to find it illustrated, and very well illustrated, in Agricola's treatise written a century before.

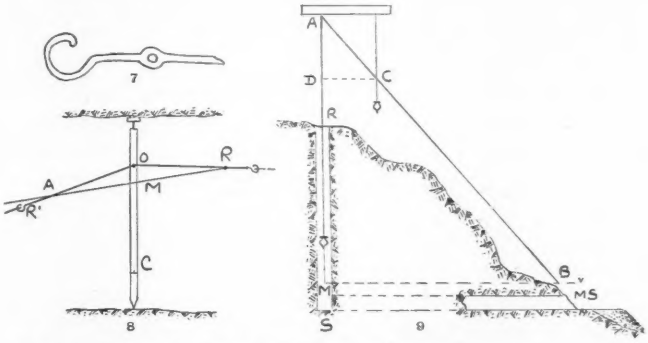


FIG. 7. Fragment of metal rod found at Mount Pangeon.

FIG. 8. Surveying instrument reconstructed from fragment shown in Fig. 7.

FIG. 9. Solution.

AC–AB–DC–AD–DR–MS = Known Elements.

$$BM = \frac{AB \times DC}{AC}$$

$$AM = \frac{AD \times AB}{AC}$$

$$RS = AM - RA + MS.$$

After the downfall of the Mediterranean civilizations, metallurgy and mining migrated northward, and in the virgin soil of northern Europe, with the passing of the Middle Ages, they entered a new stage of progress, which developed into the present industrial supremacy of the Anglo-Saxon and German peoples. The Italian Renaissance, however, assisted greatly in this process,

serving as a bridge over the huge span between classic culture and modern industrialism; but with its decline the Greek and Latin pre-eminence seems to have passed forever.

Unfortunately we cannot hope to have sufficient archeological evidence to properly appreciate the lore of the ancient economic geologist, which probably included some things at present wholly unknown.

The writer takes great pleasure in thanking Professor Alan M. Bateman for help and suggestions in the preparation of this paper.

CASTELNUOVO DEI SABBIONI,
AREZZO, ITALY.

GENESIS OF THE MICA PEGMATITE DEPOSITS OF LATAH COUNTY, IDAHO.[1]

ALFRED L. ANDERSON.

INTRODUCTION.

THE origin of pegmatites is still an open problem. Many workers no longer regard pegmatites as the product of essentially contemporaneous crystallization of minerals from magmatic solutions rich in the so-called mineralizers, but ascribe the great size of the crystals, the occurrence of rare minerals and elements, and other characteristics peculiar to pegmatites, to later replacements of an earlier formed rock essentially free from any of the mineralizers. Such an explanation has been given by Hess,[2] who develops the idea of changes in pegmatites after solidification by replacement processes and explains the enormous amount of replacement and huge size of crystals by the long-continued flow of solutions from the parent magma. Schaller [3] also proposes the belief that lithium pegmatites are not the result of an original crystallization of a magma unusually rich in the so-called mineralizers, but that they are the result of a later replacement (probably hydrothermal) of an earlier-formed rock. In a later paper Schaller [4] again discusses mineral replacements in pegmatites and explains these as due to the effect of later hydrothermal material entering and reacting on the solid rock formed during the magma process. Se-

[1] Published with permission of the Director of the United States Geological Survey and the Secretary of the Idaho Bureau of Mines and Geology. The writer wishes to express his gratitude to Dr. W. T. Schaller, to Dr. Charles Milton and to others of the United States Geological Survey for their helpful suggestions in the preparation of the manuscript.

[2] Hess, F. L.: Natural History of Pegmatites. Eng. Min. Jour. Press, vol. 120, pp. 289–298, 1925.

[3] Schaller, W. T.: The Genesis of Lithium Pegmatites. Amer. Jour. Sci., (5), vol. 10, pp. 269–279, 1925.

[4] Schaller, W. T.: Mineral Replacements in Pegmatites. Amer. Min., vol. 12, pp. 59–63, 1926.

quences of mineral replacements in pegmatites have also been worked out by Landes [5] and have been cited less directly by others.

As yet, the number of pegmatites described as products of hydrothermal replacement at high temperature is not large, but as others are studied or restudied the number falling in this group will undoubtedly show great increase, and it may be found eventually that most pegmatites have been more or less affected by such replacements.

The mica deposits of Latah County, Idaho, have been described [6] as typical occurrences of muscovite-bearing pegmatites with no mention of a replacement history. Later studies by the writer reveal, however, that these pegmatites too have an interesting paragenetic history, and that the commercial muscovite, as well as the beryl, tourmaline, garnet, and albite, were formed later by replacement of an earlier-formed graphic granite composed of microcline and quartz. The studies show further that had it not been for these later replacements, the pegmatites would have been as valueless as countless others of simple quartz-feldspar content in the surrounding region. On the contrary, these mica-bearing bodies have furnished commercial muscovite valued at more than $100,000, and at the present time one of the bodies is being prospected and mined for its beryl as a beryllium ore. It is hoped that a description of these pegmatites will contribute to a better understanding of their nature and origin and will show especially the close relationship of pegmatites to contact-metamorphic zones and to replacement veins.

GEOGRAPHIC FEATURES.

The pegmatites herein described lie from three to six miles north of Avon, in a belt that trends northward through T. 41, N., R. 2 W., Boise Meridian, in the eastern part of Latah County,

[5] Landes, K. K.: The Paragenesis of the Granite Pegmatites of Central Maine. Amer. Min., vol. 10, pp. 355–411, 1925.

[6] Sterrett, D. B.: Mica in Idaho, New Mexico, and Colorado. U. S. Geol. Survey Bull. 530, pp. 375–390, 1913; Mica Deposits of the United States. U. S. Geol. Survey Bull. 740, pp. 86–93, 1923; and Anderson, A. L.: Mica Deposits of Latah County, Idaho. Idaho Bur. Mines and Geol. Pamph. 14, 1924.

Idaho. They occur mainly along the southern slope and crest of a westward projecting spur from the Clearwater-Coeur d'Alene system of mountains in northern Idaho at elevations between 3400 and 4700 feet, A.T., and look down upon a deep embayment of the Columbia Plateau whose margin lies near Avon at an elevation of about 2500 feet, A.T.

Many pegmatites have been prospected in this region, including those on the Muscovite, Bentz, Luella, Maybe, Levi Anderson, Morning Star, Sunshine, and Avon properties, but production has come only from the Muscovite, Bentz, Luella, Maybe and the Levi Anderson, and, of these, the Muscovite has been by far the largest producer. For additional details of the properties, the reader is referred to previous reports of the district.[7]

GEOLOGIC FEATURES.

The pegmatites are enclosed in schists and micaceous quartzites of pre-Cambrian (Algonkian) age, probably in the basal formation of the Belt series, the Prichard formation. Metamorphism is much more pronounced in the vicinity of the pegmatites than elsewhere in the region, except immediately contiguous to the Idaho batholith or its outliers, and in consequence the muscovite and biotite schists and micaceous quartzites are in many places studded with pinkish crystals of garnet and locally carry much black tourmaline. To the north, away from centers of igneous activity, the character of the rock changes to argillite and argillaceous quartzite. As will be discussed later, marked contact-metamorphic action probably accompanied the intrusion of the pegmatites, although there is reason to believe that the Idaho batholith, from which the pegmatites are believed to be off-shoots, underlies the district at shallow depth. A large outlier of the batholith lies from two to three miles east [8] of the belt of pegmatites, a still larger body outcrops a few miles to the west, and a few bodies of aplite and some granitic apophyses show in the valleys within the district itself. The age generally assigned to the Idaho

[7] Sterrett, D. B.: *op. cit.*, and Anderson, A. L.: *op. cit.*

[8] Anderson, A. L.: The Geology and Mineral Resources of the Region about Orofino, Idaho. Idaho Bur. Mines and Geol. Pamph. 34, 1930.

batholith and its differentiates is late Cretaceous or early Eocene, although Ross [9] considers the batholith as probably intruded near the end of the Jurassic.

GENERAL FEATURES OF THE PEGMATITES.

These pegmatites, in common with pegmatites elsewhere, exhibit great diversity of size and form. A few have a nearly uniform width for several hundreds of feet, but most of them are characteristically irregular in size and form, and swell abruptly into lenticular or chimney-like masses from a few inches in width at the ends to as much as 40 feet in the enlarged portion. This character is displayed on the dip as well as on the strike, and always involves great uncertainty in mining. The principal pegmatite at the Muscovite mine ranges from four to six feet in width in the lowest workings about 300 feet below the outcrop, but in a stope about 10 feet above it widens to 12 feet, and at the surface enlarges to 40 feet. Mica has been mined for 500 feet along the body, but not everywhere with equal success, for in places along the strike the body pinches to almost knife-blade thickness. The Luella also shows the same irregularity. It has several branching and intersecting seams, each characteristically swelling and pinching on dip and strike, the main one enlarging abruptly into a nearly cylindrical body 30 feet in diameter. It then pinches to its original width of a few inches. A similar tendency to swelling and pinching is shown by most of the other deposits.

Most bodies conform with the schistosity of the enclosing schist and thus strike from N. 10° E. to N. 10° W. and dip steeply to either the east or west. In some, the contact between pegmatite and schist is sharp, but in others it is gradational, particularly about such bodies that are rich in quartz, muscovite, tourmaline, or minerals other than the feldspars. In contrast, those composed of graphic intergrowths of quartz and microcline alone have sharp boundaries. Such a relation of gradational contacts and sharp contacts to the character of the pegmatite filling must have a significant bearing on the genesis of the pegmatites themselves.

[9] Ross, C. P.: Mesozoic and Tertiary Granitic Rocks in Idaho. Jour. Geol., vol. 36, pp. 673–693, 1928.

In texture, too, the pegmatites show a marked variation. A cursory examination suggests two dominant textures, that of graphic granite called the graphic type and that of coarse-grained granite called the granitic type. Commonly, the granitic texture is modified by varieties of nearly pure granular quartz. Some pegmatites, and especially those of nearly uniform width, consist mainly of graphic granite. These contain little or none of the muscovite, beryl, tourmaline, and garnet, characteristic of the granitic type of pegmatite, and are valueless except for their contained feldspar. On the other hand, pegmatites resembling coarse-grained granite form the enlarged or chimney-like parts of the dikes and contain minerals of especial interest and value. Some of the pegmatites of granitic type are notably uniform in composition and texture throughout, but most of them show variation, with the footwall perhaps more feldspathic than the hanging wall, or with seams and bands of quartz and other minerals such as muscovite, beryl, or tourmaline cutting through the feldspathic portions. A few of the bodies are largely quartzose, and these may contain more muscovite, tourmaline, or beryl than the more feldspathic varieties. In general, the development of minerals other than feldspar has been in the most siliceous parts of the pegmatite.

Occurrence of both graphic and granitic types within the same body is common and this feature has an important bearing on the genetic history of the deposits. In these, the granitic type appears as a later development or as having been superimposed on the graphic type so that only " ghost-like " outlines or forms of the latter remain, or the graphic texture may be almost completely obliterated. The Luella pegmatites preserve the shadows of the graphic texture better than most of the other bodies, and the texture is clearly that of graphic granite partly obliterated by incomplete change to the granitic type, but traces of the earlier graphic texture are still plainly seen. Remnants of the graphic texture may also be found in most of the others, in some, abundant, in others, almost wanting. Each occurrence suggests an original filling of graphic granite, later more or less affected by replacing solutions. Those dikes that are now essentially graphic

granite have been affected but very little by these replacing solutions, and represent a stage similar to that once held by all the dikes. In this respect the pegmatites greatly resemble those described by Schaller [10] from San Diego County, California.

Mineralogy.

When the individual minerals and their relations to one another are studied in detail, additional evidence is afforded of replacement which is so strongly suggested from the patches or shadows of graphic texture found in so many of the granitic bodies. The relations indicate first, an original crystallization of quartz and microcline as ordinary graphic granite; then, as solutions permeated upward through the bodies, a series of replacements occurred in which the earlier rock was partly replaced, first by albite, and second by quartz, followed in turn by muscovite, tourmaline, beryl, garnet, and other minor accessory minerals. Quartz is the only mineral that definitely appears in more than one stage, being deposited abundantly near the beginning and then more or less continuously, but in minor quantity, to the end. Other minerals also overlap, but to a much lesser extent.

Microcline.—It is only in the graphic residuals or in the dikes composed wholly of graphic granite that microcline is to be found. Even then, it is rarely found in a pure state, but usually shows all stages of replacement by albite, the least so in areas most distant from the granitic areas or the channels through which later solutions permeated. The microcline cannot be readily distinguished from the younger feldspar except microscopically, as the feldspars all have the same white color. Albite may be recognized in places by its polysynthetic twinning, often distinctly shown megascopically on basal cleavages. Orthoclase may possibly be present in some of the graphic granite, but none was found in the sections studied. It is more than likely that any orthoclase originally deposited has subsequently inverted to microcline. Schaller [11] believes that high-temperature potassium feldspar (possibly ortho-

[10] *Op. cit.*, Amer. Jour. Sci., pp. 269–276.
[11] *Op. cit.*, Amer. Min., p. 60.

clase) is always formed first in the pegmatites and that on cooling there is an inversion to microcline, the low temperature modification. The quartz associated with the microcline in the graphic intergrowths is always subordinate. In some dikes the microcline is the main filling and the quartz forms only sporadic intergrowths.

Albite.—Albitization of the graphic granite represents the first stage of the replacements, the albite ($Ab_{97}An_3$) replacing first the microcline and to lesser extent the quartz. Incipient stages of the replacement are shown in Fig. 1, where irregular veinlets and stringers of albite occur in the microcline. These small veinlets extend in every direction and are only partly controlled by the twinning and cleavage of the microcline. These veinlets are all in optical continuity and extinguish together between crossed nicols. As replacement advances, the veinlets broaden and in the widest part contain only minor remnants of the microcline. Such replacement progresses until the microcline is entirely, or almost entirely, replaced by one large crystal of albite. Such replacement may yield an apparent graphic intergrowth between the albite and quartz, especially in the Luella pegmatites, although in general the albite has tended to form its own crystal borders with destruction of the graphic texture.

Quartz.—The formation of abundant quartz marks the next stage in the development of the pegmatites. It is likely that some quartz was deposited during the albitization interval, but most of it was clearly deposited later. Veinlets of the smoky gray quartz in the albite and microcline are common and the irregularity of these seams or veinlets strongly suggests replacement. In some pegmatites, for example the Bentz, the dike has been rendered highly quartzose and retains only a subordinate amount of feldspars. The Muscovite pegmatites likewise show an extremely siliceous zoning with some masses of nearly pure quartz, grading into portions with increasing amounts of feldspar. The parts of the pegmatites with granitic texture always show an increase in quartz content over that in the earlier graphic type. Albite has not always been easily replaced and it is not uncommon to find crystals with good outlines entirely surrounded by quartz.

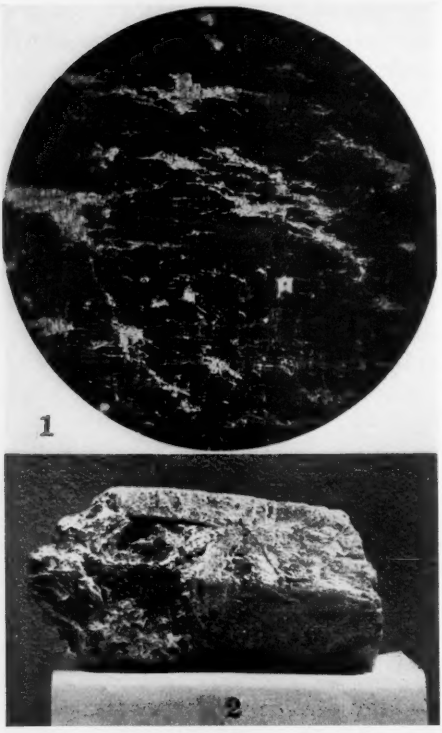


FIG. 1. Microcline showing incipient replacement by irregular seams and veinlets of albite. The albite in all veinlets is in optical continuity and if replacement were to progress farther the veinlets would unite to form a single large crystal of albite. Note that the twinning and cleavage of the microcline has little to do in directing the replacement. Crossed nicols, $\times 25$.

FIG. 2. Illustrating the typical appearance of larger beryl crystals. This crystal in common with most others has a partial core of unreplaced quartz, feldspar, and muscovite, shown at the left end of the crystal where the beryl has not completely enclosed it. The core does not extend entirely through the crystal, for the other end is composed almost wholly of pure beryl. The idiomorphic form assumed by the beryl during the replacement is easily seen. Length of specimen, about eight inches.

Most of the quartz was apparently deposited between the albite stage and the muscovite stage which followed, although some deposition continued throughout, as quartz also forms veinlets or fills fractures in the broken or shattered minerals of later age. The amount of quartz so deposited is very small compared with that at the beginning.

Muscovite.—Muscovitization follows the quartz, for the muscovite flakes and books replace the quartz as well as the feldspars, and replace each apparently with equal ease. It is during this stage of pegmatite development that the large commercial books of muscovite, ranging up to 18 inches in diameter, have been formed. These crystals are commonly as much as three inches thick and consist of muscovite of good quality from which large sheets may be trimmed. In one of two places near the walls biotite has been noted in crystals less than three inches in diameter. Development of biotite in place of muscovite has probably been due to assimilated material from the wall, but in general muscovite is the only mica in the pegmatites.

Crystals of muscovite of small unmarketable size are sporadically scattered throughout the granitic type of pegmatite and to some extent also in the graphic type, but the larger crystals are usually confined to the most siliceous parts of the dikes. This is especially true at the Muscovite mine, where the mica lies in the quartzose zones and occurs at irregular intervals in large clusters that are loosely united by narrow seams, or are scattered at random. At the Luella, the mica is scattered to some extent throughout the dikes but crystals attain their largest size near the hanging wall where the pegmatite is generally the most quartzose. Similar relations exist at the Levi Anderson and the Maybe where the muscovite crystals occur in the quartzose hanging wall. In the Maybe the muscovite tends to occur in seams, best developed in the quartzose parts. The Bentz does not differ from the others. The entire body is highly quartzose, in consequence of which the mica shows a more regular scattering.

Replacement by muscovite has not been confined to the quartz and feldspar of the pegmatites alone, but has extended in places into the wall as well. Crystals of mica as much as five inches in

diameter penetrate the schistose wall at the Muscovite pegmatite. This mica is generally darker than that within the pegmatite, differing from it in having a dark bronze to nearly black color, but thin sheets are colorless. The relation of the penetrating crystals of mica to the wall border admits of no other interpretation than that of replacement, and by the same solutions as those from which the muscovite in the pegmatite was formed. Tourmaline or beryl, or both, commonly accompany the muscovite and show similar relations to the wall. At such places the wall shows intensive metamorphism or alteration for several feet from the contact, and it becomes evident on close scrutiny that the pegmatite was considerably enlarged as the result of wall replacement. At no place does the muscovite show the decrease in size at the contact which would be expected at the chilled border in the case of simple crystallization from a magmatic solution.

Tourmaline.—Tourmaline is an abundant mineral in some of the pegmatites; in others it is abundantly developed in the walls. Its deposition was later than the muscovite, for not only do its crystals show all stages of replacement of quartz and feldspar, but they show partial to complete replacement of the muscovite crystals as well. In common with most of the later minerals the tourmaline tends to develop its own crystal form during the replacement. The crystals project through and across the earlier minerals and show more clearly than most other minerals their superimposition on the granitic and modified graphic rock because of the large size attained by them.

The pegmatites of the Luella mine show the most interesting as well as the most spectacular development of tourmaline crystals. Not only is tourmaline abundant in the pegmatites, but some crystals attain great size, one crystal measuring as much as eight feet long. Crystals between one and three feet in diameter are common. The larger tourmalines are barrel-shaped; the smaller ones have rather blunt terminations on one end and long slender spire-like forms on the other; prismatic faces are striated vertically. Although most of the tourmaline has good crystal outlines, some of the smaller grains and masses are more or less irregular where they fill fractures in quartz or albite. All the tourmaline has a

vitreous luster and a black color resembling coal on broken surfaces. The crystals are mostly somewhat shattered and the fractures are filled with late quartz. In the Luella the tourmaline crystals are scattered throughout the pegmatites, but with closer groupings along either wall. Crystals occur in the wall as well, but in less abundance. The pegmatite of the Muscovite mine contains very little tourmaline, but its enclosing wall is especially rich. That at the Bentz mine has a few small crystals, less than three inches long, also a considerable number developed in the wall. Most of the others have sporadic crystals of tourmaline. In general, the tourmaline, like the muscovite, prefers the more quartzose portions of the pegmatite, that is, in the zones along which the later solutions from below have moved. Tourmaline in the wall followed extensive earlier silicification.

Beryl.—Beryl occurs in some abundance in the pegmatite at the Muscovite mine and is also reported in the Levi Anderson, but not elsewhere. The crystals range in size from microscopic to as much as eight inches across, and some attain a length of as much as 18 inches. The color is pale yellow-green, but it is not uniform and crystals may change in depth of color from the interior outward, or from one end to the other. Some of the smaller crystals are nearly white. Crystals vary from translucent to transparent, but unblemished crystals suited for gems of high quality were not seen. Like the tourmaline, the beryl also has been somewhat broken and the fractures healed with a younger generation of quartz.

The relations of the beryl to the other minerals indicate that it too was deposited late by replacement and that it has replaced not only quartz, feldspar, and muscovite, but tourmaline as well. Its relation to the garnet only is not precisely determined. It tends to form well-shaped prismatic crystals in replacing the earlier minerals, but its terminations are incomplete. The beryl has been less successful in general than the tourmaline in replacing earlier minerals, and the larger crystals especially hold engulfed masses of quartz, albite or microcline, and muscovite, with here and there small tourmaline crystals. Interior cores of the earlier pegmatitic matrix are the rule rather than the exception in the larger crystals,

and only the smaller crystals, less than an inch in thickness, are uniform throughout. A large crystal of beryl with such a core is illustrated in Fig. 2. At one end of the crystal the beryl is seen partly surrounding a matrix of muscovite, albite, and quartz. This matrix extends far into the crystal, but not entirely through, for the other end has but a faint trace of quartz and albite. Of all the earlier minerals, muscovite seems least susceptible to replacement by beryl.

Deposition of beryl has followed the same zones as the earlier albitization, silicification, and muscovitization. It is apparently confined mainly to the muscovite-rich portions of the pegmatite. In the lowest part of the pegmatite at the Muscovite mine crystals lie in all positions and directions across the body, and some of large size project into the walls. It is there accompanied by large plates of muscovite. At the surface, the beryl occupies any position near the siliceous and mica-rich walls of the body. In many places through the body the beryl forms as much as one-third of the matrix.

Garnet.—The position of the garnets with respect to the beryl is not precisely known, as the two were not found in the same bodies. At the Luella, where the garnet is especially abundant, it shows replacement of tourmaline as well as of the other earlier minerals, and itself is somewhat fractured with the fractures healed by quartz. Its position there is analogous to that of beryl in the pegmatite of the Muscovite mine, and it is probable that the two are not far removed in point of time. The garnet appears to replace feldspar and muscovite readily and even to replace quartz, but replaces tourmaline with difficulty. The garnet tends to assume its own crystal form (imperfect trapezohedrons) during the replacement, but in part it forms irregular grains and masses in quartz, or cuts across tourmaline crystals or engulfs them, if they are sufficiently small. Euhedral outlines are especially prone to develop against the albite and the muscovite. The crystals seldom attain an inch in diameter, or even a half inch, except at the Sunshine, where several are nearly three inches in diameter. The color ranges from pinkish to purplish rose-red and nearly black, but as the crystals are much traversed by cracks

which render them friable, granular, and somewhat opaque, they have no value as gems. Shannon,[12] who has examined the garnets in detail, finds them to belong to the almandite-spessartite series, with index of refraction of 1.818, and with a composition of 63.61 per cent. almandite, 32.95 per cent. spessartite, and 3.44 per cent. pyrope.

The garnet is widely scattered through the Luella pegmatite but shows greatest concentration near the walls, where it is mostly segregated into irregular seams or bunches. It is also widely distributed in the walls of the pegmatite, showing there the same relations to the minerals of the altered country rock as to the corresponding minerals within the pegmatite. Additional data on its occurrence in the wall rock will be given in a later section. Garnet is also abundant in the Maybe body, where it is scattered through the dike matrix and especially segregated in the mica-bearing seams of the quartzose footwall. Garnet also prefers the more siliceous portions of the pegmatites for its development.

Accessory Minerals.—Several minor accessory minerals, including apatite, magnetite, and autunite (?), were recognized, but it was impossible to obtain their precise relations to the other minerals since they occur in general as minute grains or crystals in the quartz or feldspar. Apatite and autunite (?) both appear to be minerals of a late stage. The late quartz may be included in this list, for in most bodies it can be recognized in small quantity in the fractures of the minerals described above; but in one pegmatite, at least, it occurs in large quantity and has been instrumental in impoverishing the body by changing it largely to granular quartz. Deposition of quartz then closes the chapter on the formation of the pegmatites.

Wall Alteration.—Extensive wall alteration has already been mentioned and because it is so well displayed about some of the bodies it is worthy of special consideration. Its effect, as mentioned earlier, is seen particularly about the pegmatites which have been internally affected by the passage of solutions or those rich in the so-called mineralizers, while in contrast the effect is almost

[12] Shannon, E. V.: Notes on Garnets from a Pegmatite in Idaho. Amer. Min., vol. 7, pp. 171–172, 1922.

lacking about bodies of graphic granite. This relation suggests that the solutions responsible for the replacements within the pegmatites were also the cause for the changes induced in the country rock.

Mention has been made of the grading of pegmatite into schist about some of the bodies and of the replacement of some of the schistose wall by the later minerals of the pegmatites themselves. Other changes become obvious when the country rock is examined more closely even at some distance from the contact. A description of the wall rock about several of the pegmatites will make these relations clear.

The country rock bordering the pegmatite at the Muscovite mine is a typical muscovite schist, composed of uniformly large flakes of muscovite, approximating one-fourth inch in diameter and locally much larger, alternating with beds containing biotite. The abundance of muscovite as compared with that in the metamorphosed rock elsewhere in the general region is the most striking character of the rock. On cross fractures, quartz and feldspars may be detected between the muscovite layers, but apparently they play a minor rôle. In places, the schist holds abundant metacrysts of black tourmaline, in elongated crystals up to two inches in length. These crystals have poor terminations, or rarely rhombohedral faces, but do have excellent prismatic faces, nine in all, with three alternating faces showing much larger development and giving the crystals an essentially three-sided form. These crystals contain numerous inclusions of the schist and are obviously a late introduction into the rock. Microscopic examination shows a sequence of events in the wall similar to that within the nearby pegmatite: first occurred albitization of the wall rock, followed by silicification, which in places is still well preserved, and then extensive muscovitization through replacement of both the quartz and albite by muscovite. Near the contact, muscovite has developed locally as large crystals, which, as mentioned previously, project from the pegmatite into the wall and replace the wall matrix. Tourmalinization followed in sequence as indicated earlier. Only a minor quantity of beryl has entered into the enclosing schist.

Alteration of the wall is even better displayed adjacent to the Luella pegmatites. At a dozen feet or more from the pegmatites the country rock is a glistening muscovite-biotite schist with scattered needles and rods of black tourmaline. Nearer the pegmatites the country rock changes to a highly contorted quartzose rock still micaceous and containing numerous small pinkish garnets similar to those within the pegmatites. It also contains abundant tourmaline. The quartz, garnet, and tourmaline show progressive decrease in quantity outward from the contact, and the muscovite, garnet, and tourmaline crystals also show a corresponding decrease in size. In places the pegmatite grades into the wall, especially where silicification has been most intense. Microscopic studies again reveal a sequence of events in the contact zone similar to that within the pegmatite. Albitization of the wall rock represents the first stage of the alteration, but this stage has been almost lost through the following extensive silicification. Then muscovite developed in the walls, followed in turn by tourmaline and by garnet, each by replacement. These relations suggest a large transference of soda, potash, boron, and water from the pegmatitic bodies into the enclosing wall, probably by the same solutions that permeated through the pegmatites themselves and caused the later replacements therein.

SUMMARY AND CONCLUSIONS.

A study of the mica deposits of Latah County, Idaho, has yielded an interesting example of the replacements in pegmatites lately recognized by Schaller, Hess, and others, as playing an essential rôle in the normal history of pegmatite development. From structural, textural, and mineralogical relations, an interesting genetic history has been worked out in the case of the Latah County bodies, which shows clearly the dependence of the formation of certain minerals on a later passage of hydrothermal solutions from which these minerals have been deposited mainly by replacement of an earlier dike-filling. The Latah County bodies show first an early crystallization of quartz and microcline as ordinary graphic granite, the microcline perhaps having inverted

from a higher temperature modification of potassic feldspar. Following this early crystallization, the bodies were invaded by solutions escaping from the magma at greater depths and these found that the hot, newly intruded dikes offered the least resistance for their upward journey. As these solutions moved upward through the bodies, they reacted with the solid rock formed during the magmatic process and replaced, or partly replaced, the graphic filling with a new group of minerals and in so doing destroyed, or partly destroyed, the graphic texture, causing instead the development of the coarse, granitic texture, or locally nearly pure bands of quartz. During this interval the rarer and better crystallized minerals were formed. The first of the high-temperature replacements involved extensive albitization during which the microcline, and to some extent the quartz, were more or less completely replaced by albite. This stage was perhaps in part accompanied by the deposition of quartz, but extensive silicification came mainly later and persisted in a minor degree to the end. During this stage many bodies were rendered highly quartzose. Muscovitization closely followed the main quartz deposition and large crystals were formed by replacing all earlier minerals. Then followed in turn the development of tourmaline, beryl, and garnet, each assuming its own characteristic crystal form as each more or less successfully replaced the earlier matrix.

As the composition of the hydrothermal solutions was not the same in each dike and as the volume of the solutions passing through each was not the same, the numerous bodies exhibit notable differences among themselves. Some contain beryl, some garnet, and most of them variable amounts of tourmaline. Thus, the solutions differed in the presence or absence of beryllium and in the variable quantities of boron and other elements. All are alike in that all solutions were sodic and contained much silica, and commonly considerable potash, which entered into muscovite. Most dikes in the general region were only slightly affected by the passage of these later solutions and so remain mainly as graphic granite. Other bodies, because of the passage of greater volumes of solutions, have had their original textures partly obliterated and

in extreme cases have had the graphic texture almost entirely replaced by the coarse granitic texture.

The pegmatites in the general region clearly illustrate the dependence that must be placed on the later solutions for the development and occurrence of most pegmatitic minerals. Evidence of later replacement should serve as a useful index to exploratory work, for surely those bodies that show little evidence of such replacement need receive little consideration, and prospecting had best be directed on bodies which show ample evidence of hydrothermal action. Occurrence or absence of albite should be helpful in ascertaining whether such solutions have passed through the rock. Presence of graphic granite need not necessarily disqualify a dike from a commercial standpoint, for other parts of the same body may pass into the other textural type. Only rarely has the channel for the passage of the solutions extended throughout the entire dike, but it has been more generally confined to a comparatively small part such as the chimney-like swellings.

Passage of the late solutions from below has not always been within the dike body, whether in the center or near either of the walls, but in many cases the solutions have permeated into the wall or country rock, inducing there a series of replacements identical to those within the pegmatite bodies and leaving the same list of minerals in the same order of formation. In places the wall replacement has been extensive and minerals have attained such large size that it is not possible to tell how much of the body belongs to the original dike filling and how much is due to wall replacement. As most of the commercial shoots are in the chimney-like swellings of the pegmatites, it seems likely that most of these are in part the result of more extensive replacement of both the original dike and the wall about main channels of solution movement.

The metamorphism shown about each of the pegmatite bodies is clearly dependent upon the volume and character of the solutions that have escaped from the channelways within the dikes. As mentioned before, the genetic history of the metamorphism is identical with the replacement series within the pegmatite, the most notable difference being in structure and texture. Thus, the

pegmatites show a close relationship in genesis to contact-metamorphic zones, and the main difference between the two depends on whether the later solutions have followed the pegmatite bodies and have caused the replacement therein, or whether the solutions have entered into the country rock, causing there the metamorphic zones.

As some of the dikes have been rendered highly quartzose as a result of the replacements or deposition from the late solutions, there exists also a close relation between pegmatites and hypothermal replacement-veins. Additional data in confirmation of this relation have been obtained by a study of such relations over a much larger area.

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HEMATITE IRON ORES OF SIERRA LEONE, WEST AFRICA.

KATHARINE FOWLER-LUNN.

INTRODUCTION.

THE writer has spent the past two winters doing geological work in the central part of Sierra Leone, where large deposits of high-grade hematite have recently been found. This small British Colony, about 27,000 square miles in area, is bounded by Liberia on the east, French Guinea on the north and east, and the Atlantic Ocean, with the excellent harbor of Freetown, on the south. The climate is tropical with high humidity and temperatures around 90°, a rainy season from April to October, and an average rainfall of about 100 inches. Sierra Leone was thought to contain no minerals of commercial importance until 1928, when the Geological Survey, under the direction of Major N. Junner, discovered gold, platinum, chromite, hematite, and smaller deposits of corundum, rutile, graphite, and bauxite.[1, 2] Discoveries in connection with, but independent of these first finds, have been made ever since, and mining is now rapidly developing.

The natives in previous generations smelted iron ore throughout Sierra Leone,[3] but they are not only loath to tell the sources of the iron used, but appear to have forgotten the art of making steel. In consequence of the findings of high-grade banded ironstones in three places in the central schist belt, or Kambui schists, of Sierra Leone (at Sakasakala, Keimadugu, Sokoya, and Nerekoro), the Government closed to prospecting a large area in which the hematite occurred. It was through the suggestion of Major Junner that the author undertook the mapping of the continuation

[1] Junner, N. (Present Director of the Gold Coast Geological Survey): Geology and Mineral Resources of Sierra Leone. Min. Mag., vol. 42, p. 73, 1930.

[2] Geological Survey of Sierra Leone, Reports, 1928, 1929, 1930.

[3] Dixey, F.: Primitive Iron Ore Smelting Methods in West Africa. Min. Mag., vol. 23, pp. 213–216, Oct., 1920.

of the hematite deposits in 1931, the Government of Sierra Leone contributing a sum towards expenses. The deposits proved much larger and richer than anticipated, so that the Government has continued to keep the area closed, and will eventually give development rights to some commercial company willing to exploit the ore. The problems concerning the origin of the hematite deposits, and the geologic history of the range in which they occur, have been followed up independently by the author through traverses of the range, and the study of thin sections. They were also constantly borne in mind during the past year while geological investigation was being carried on for a British gold mining concern (Maroc, Ltd.) in other parts of the same crystalline belt, continuations of the same hematite deposits having been encountered far to the south of those originally mapped.

GENERAL GEOLOGY OF SIERRA LEONE.

Sierra Leone consists of a low-lying coastal plain about 100 miles in width, back of which is a hilly to mountainous region, a semi-plateau, from which higher mountains rise.[4] Freetown and its environs are made up of a mountainous mass of norite, gabbro, and anorthosite.[5] Elsewhere, great belts of ancient schists stretch across Sierra Leone, cut off from one another by intrusive granites. The age relationship of these "roof pendants" of schist has not been determined.[6] In French Guinea to the north, rocks containing Silurian fossils overlap the schist-granite belt, marking the age of the Sierra Leone rocks as pre-Silurian.[7] The hematite deposits under discussion are situated about in the center of Sierra Leone in the belt of Kambui schists. (Fig. 1.)

[4] Dixey, F.: The Physiography of Sierra Leone. Geog. Jour., vol. 60, p. 41, 1922. Reports of the Geological Survey of Sierra Leone; 1919, 1920, 1921.

[5] Dixey, F.: Norite of Sierra Leone. Quar. Jour. Geol. Soc., vol. 78, Pt. 4, 1922. Junner, N.: Norite of Sierra Leone. C. R. Int. Geol. Congress, 1929, vol. 2; pp. 417–33.

[6] See Junner, *op. cit.* (1), for fuller description of rocks and description of provisional geological map.

[7] Sinclair, J. H.: Discovery of Silurian Fossils in French Guinea. Jour. Geol., vol. 36, 1928, pp. 475–478.

Physiography.—The mountainous region in which the hematite deposits occur is slightly higher than the surrounding granites, owing to the resistance to erosion of the Kambui schists. The drainage has been superposed from an earlier erosion cycle, so that some of the larger streams cut across the structure of the

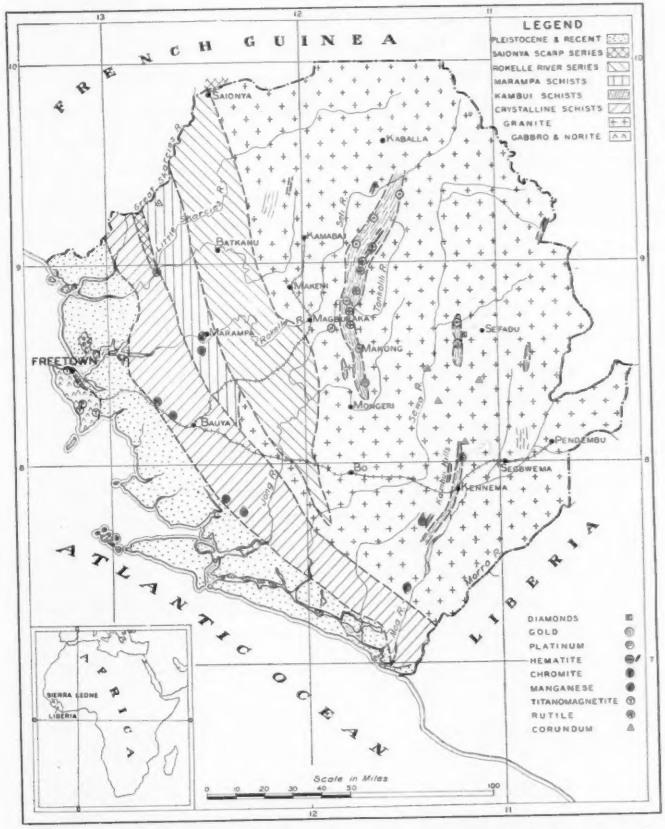


FIG. 1. Provisional geological map of Sierra Leone showing location of hematite deposits. Adapted from Provisional Geological Map of Sierra Leone. See Junner, *op. cit.*, for complete description.

mountain mass at right angles. The granites to the east and west form a plateau topography, capped by domes or "inselbergs," in contrast to the rough, jagged dissection of the schist region, whose hills follow the north-south strike of the steeply dipping rocks. The hematite deposits are only 110 to 130 miles from the coast, so that a railroad could be readily constructed across the coastal plain belt, thence through the gorges of the superposed streams, directly to the iron formations.

Rock Formations.—The determination of the geology of this region is difficult on account of dense forests and a superficial covering of laterite and thick soil. However, the hematite is more resistant than the other parts of the formation, producing hills and ridges that are dissected by several transverse stream valleys. Sections along these streams permit the approximate delimitation of the hematite, even though the actual contacts are seldom visible.

The schist belt in which the hematites occur is about fifty miles long, with an average width of ten miles. Various rocks are found, ranging from hematite to banded ironstones, sandstones, quartzites, conglomerates, hornblende schists, mica-, talc-, and chlorite-schists, fine and coarse grained amphibolites, as well as schists of intermediate types and questionable origin. Some of the formations are of sedimentary origin; others are possibly old volcanics or highly metamorphosed basic intrusives with obscure history. These rocks now stand vertically, or dip steeply to the east. The schists show various effects of the granite intrusives. Some appear to have been impervious, while others were invaded and metamorphosed by the end stage differentiates of the granite, consisting of tourmaline pegmatites and auriferous quartz veins.

THE HEMATITE.

In the northern part of the schist belt there is one main bed of hard, massive, blue to brick-red, banded hematite which has been traced for a distance of twelve to fifteen miles, showing an average width of 1000 feet. (Fig. 2.) The actual contacts

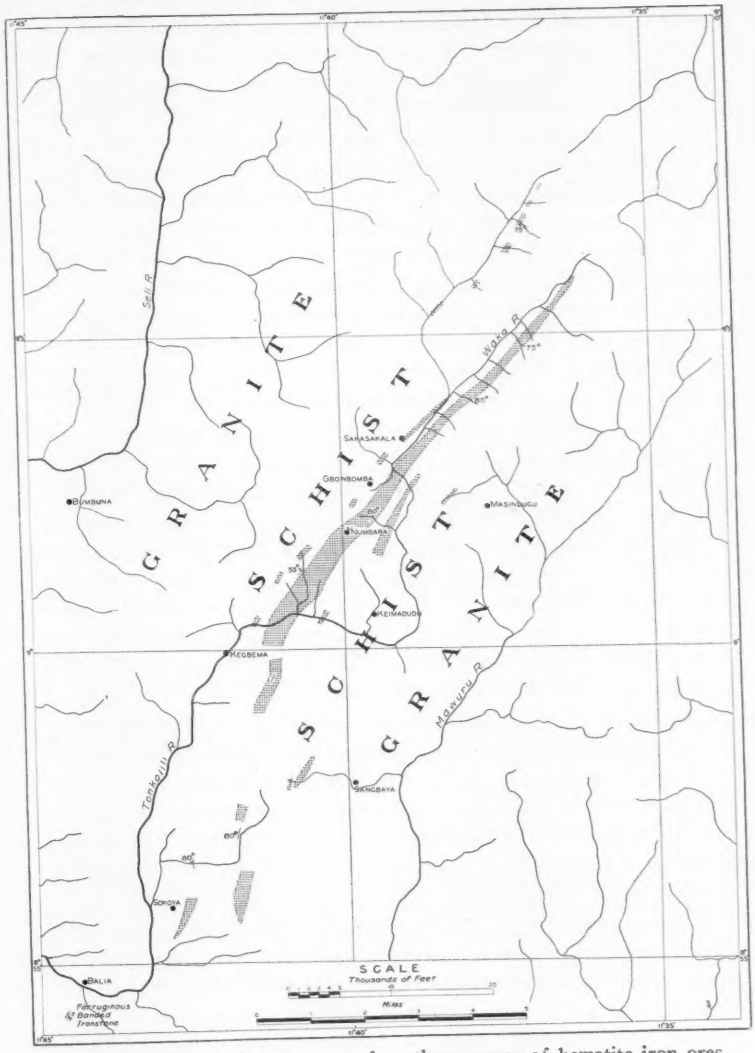


FIG. 2. Reconnaissance map of northern group of hematite iron ores of Sierra Leone. Crosshatching represents approximate boundaries of hematite.

have not been observed, but streams have cut into the banded hematites across the strike, revealing cliffs of ore up to sixty feet in height. The width of the surface float is considerable in places. Also, the height from the tops of the ridges of hematite to the bottoms of the stream beds where iron ore is exposed, is as much as 500 feet, suggesting that the iron ore should have considerable continuance in depth. These appears to be no change in the character of the ore from the highest to the lowest points. No drilling has been done to date, and since the work has been necessarily of a reconnaissance nature, only a rough estimate of the enormous mass of this main ore bed can be made, the figures running far into the millions of tons.

In addition to the main deposit, there are four smaller parallel beds of hematite. These have not been as easy to trace, but are of equally high grade. Banded ironstones of lower grade are found towards the southern and western side of the schist belt. There is evidence that the high-grade iron formations are continuous, perhaps intermittently, throughout the entire length of the schists, for areas of rich ore are found in several places many miles to the south of the main deposits, one place in particular having been encountered where high grade ore outcrops for over a mile along a traverse line. This is only one of many indications that the hematite is even more extensive than was revealed by the mapping of the main beds to the north.

Analyses.—From the specimens collected for thin sectioning and geological study, the Government of Sierra Leone had 38 chemical analyses made by the Imperial Institute in London. These analyses show that the iron ore runs consistently high in iron oxide: 80 per cent. to 90 per cent. Alumina is low, averaging from 1 per cent. to 3 per cent., except in the lateritic samples. Silica rarely exceeds 3 per cent., except in the specimens of the siliceous banded ore. Manganese is mostly less than 0.1 per cent., titania averages 0.1 per cent., and sulphur runs around 0.03 per cent. Phosphorus is the only questionable impurity; some of the ores are of Bessemer grade, and others are over the Bessemer limit. The variable phosphorus content may be explained by the fact that the specimens were collected at the surface, and not

primarily for mining determinations. The following are three typical analyses:

	19	29	43
Fe_2O_3	89.73	89.28	89.78
Al_2O_3	1.44	1.98	4.86
MnO	0.02	0.07	0.04
TiO_2	0.08	0.10	0.10
SiO_2	2.50	3.19	0.74
P_2O_5	0.04	0.07	0.05
S	0.02	0.02	0.03

19. Numbara Hill.
29. Tributary No. 4, Waka River.
43. Near top of hill, Kegbema.

ORIGIN OF THE HEMATITE.

Since contacts between the hematite and the surrounding rocks are poor and indistinct, and the sections so far studied have given few clues to the history of the iron ore, it seems best at this point merely to list the possibilities of origin of the ore, without going into detail. It is hoped that further work in the ore belt, together with their development, will clear up some questionable points.

Possibilities of Origin of Sierra Leone Hematite.

1. Original rocks were lean iron ore formations interbedded with lava flows.
   a. Secondary enrichment of lean ore by weathering.
   b. Secondary enrichment of lean ore by basic dikes or other intrusives.
2. Original rocks were lean iron ores bounded by intrusive basic sills.
   a. Secondary enrichment of lean ore by weathering.
   b. Secondary enrichment of lean ore by emanations from the basic sills at the time of intrusion.
   c. Secondary enrichment by later basic dikes or other intrusives.
3. Original rocks were sedimentary formations, possibly sandstones, replaced by iron oxide with or without secondary enrichment.
4. Original rocks were basic igneous formations, later replaced by iron ore, with all the possibilities of enrichment listed above.

Although it may be presumptuous to discuss the possibilities of origin of the hematite with the limited data now at hand, it

seems as if some of the possibilities listed can quickly be eliminated. The chemical analyses made from the siliceous phases of the iron formation show that the amount of alumina is the same in the high-grade ore as in the sandy phases. This would appear to eliminate No. 4, for if the original rock has been igneous, there should be a higher percentage of alumina in the low-grade ore. Also, in one place the hematite grades into a sandstone, and highly siliceous banded ironstones are found not far from the iron ores, indicating a sedimentary origin of the original bed.

If interbedded lavas or later intrusives and their emanations had been the main cause of the enrichment, it would be expected that the analyses would show higher titania, phosphorus, and sulphur—at least in the low-grade ores. The basic intrusive rocks in the vicinity carry variable amounts of pyrite, and end-stage quartz veins associated with the granite carry tourmaline, and commonly pyrite and gold. None of these rocks have been seen to permeate the hematite. Possibly the hematite may have proved impervious to them, for the analyses do not appear to carry expectable elements that are associated with these later intrusives.

The amphibolitic rocks, commonly found on both sides of the hematite but never in actual contact with it, are so recrystallized that their origin is uncertain. They may have been intrusive sills or lavas. They are cut by later coarse-grained amphibolitic rocks, as well as by the quartz veins and pegmatites associated with the granite.

The fact that the hematite is a continuous formation, paralleling sandstones, banded ironstones, and coarse conglomerates, indicates a probable sedimentary origin of the original iron-ore formation. The presence of conglomerate adds the possibility of an erosion interval during an early phase of the history of the ore, and secondary enrichment by weathering processes before the beds reached their present position. It is difficult to visualize secondary enrichment to the necessary depth under present conditions, since the nearby rocks of sandy character have not been affected, and many of the adjoining amphibolitic rocks are absolutely fresh. Lateritization of the rocks on the surface rarely

exceeds twenty-five feet; however, a sandy bed could have been permeable to greater depths.

The simplest explanation of the origin of the ore seems to be secondary enrichment of a lean ore formation when the original beds were in a more nearly horizontal position. An early erosion surface is represented by the conglomerate interbedded with the sandstones and banded ironstones. Later enrichment may also have occurred. This conclusion is merely a temporary working hypothesis, since there are many other factors, impossible to determine with the scanty evidence now at hand, that may have entered into the process of enrichment.

CONCLUSION.

The hematites of the central schist belt of Sierra Leone are deposits worthy of economic attention, since they represent high-grade iron-ore reserves running into many millions of tons. They are easy of access, but are as yet absolutely undeveloped. The problems in connection with their origin are of unusual interest.

FORMATION OF MARTITE AND OTHER IRON OXIDES IN SIDERITIC ORE OF THE MARQUETTE DISTRICT, MICHIGAN.

F. WIENERT.

INTRODUCTION.

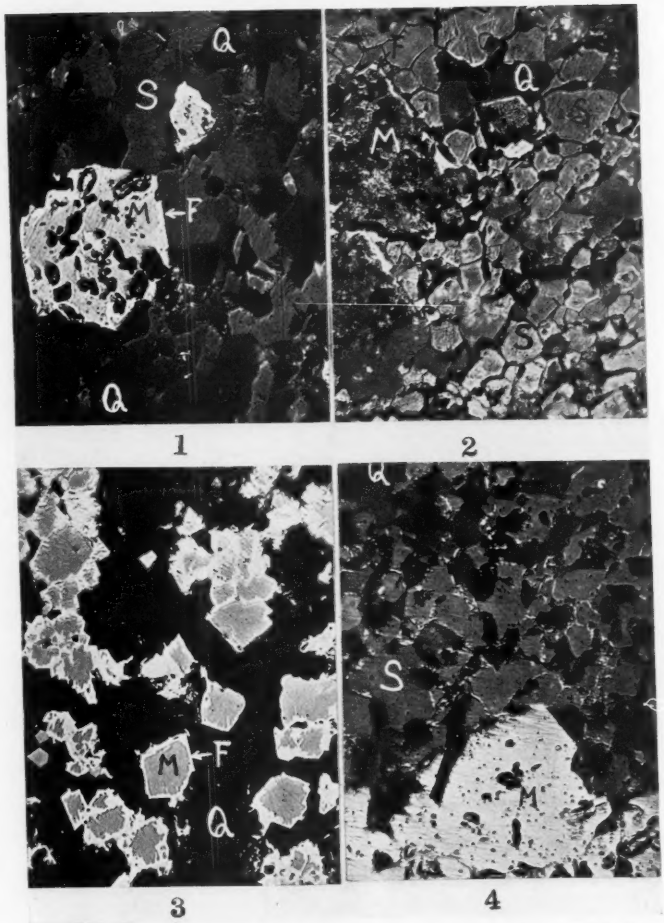
THE present paper describes the oxidation of siderite and magnetite in sideritic ore from the Marquette district. The alteration was studied in a considerable number of samples from drill cores and from outcrops around an open pit. The occurrence of martite, as the replacement of magnetite by hematite is called, was of special interest. This mineral appears under a great variety of conditions but is generally considered to be a product of oxidation. Gruner [1] thinks that in the Lake Superior iron ores the oxidation was mostly effected by hot ascending water with the formation of hydrogen. In the present instance, however, the oxidation proceeded from the surface downwards and therefore was probably caused by descending water carrying oxygen.

IDENTIFICATION OF THE CONSTITUENTS.

The specimens of the ores were examined in polished sections. The mineral formed by the oxidation of magnetite was identified as martite and distinguished from ferromagnetic oxidized magnetite because it has the white color of hematite in vertical incident light (Fig. 1), shows blood-red internal reflections like hematite, and also behaves like it against etching reagents.

A special procedure was applied, in addition to the usual methods, to distinguish the various constituents. The polished sections were heated to red heat in an open crucible for several minutes. By this roasting, ferrous carbonate is partly decomposed into oxide which makes the entire siderite opaque, so that

[1] Gruner, J. W: Hydrothermal Oxidation and Leaching Experiments. ECON. GEOL., vol. 25, pp. 697–719, 837–867. Additional Notes . . . vol. 27, pp. 189–205.



FIGS. 1–4. Polished sections. *M*-magnetite; *F*-martite; *S*-siderite; *Q*-quartz.

FIG. 1. Gray sideritic ore, polished. × 320.
FIG. 2. Gray sideritic ore, roasted after polishing. × 300.
FIG. 3. Black oxidic ore without siderite. × 320.
FIG. 4. Brown ore. Beginning of hydrating oxidation. × 320.

it reflects more light and appears bright in vertical incident illumination after the treatment (Fig. 2). A high temperature for a long time must be avoided, or the carbonate will entirely decompose and pits will result. Magnetite is superficially oxidized to ferric oxide by the treatment and assumes a rough or matte surface. Martite or hematite stays unaffected. The polished surface of quartz is not influenced either, but sometimes it is brightened by reflections from partly decomposed carbonate underneath the surface. Large areas of quartz are split up into the individual crystals. This opening of the boundaries probably depends on the conversion point of the α-crystals into the β-form at 572° C., which is accompanied by a change in volume of 2 per cent.

ORIGINAL SIDERITIC ORE AND ITS ALTERATION PRODUCTS.

Gray Sideritic Ore.—The majority of the samples were gray sideritic ores, which did not show effects of alteration except for the formation of martite. The color varies from dark to lighter gray in different localities of the deposit. This is caused by a greater or less content of dark magnetite. The total iron content of about 32 per cent is not considerably influenced by the varying ratios of siderite and magnetite. The mineralogical constituents of several lots are estimated to be as follows:

Quartz (SiO_2), 36 per cent.; siderite ($FeCO_3$), 40 per cent.; magnetite (Fe_3O_4), 17 per cent.; martite (Fe_2O_3), 2 per cent.

The siderite contains magnesium and manganese carbonates in solid solution, since chemical analyses indicate the presence of both isomorphous carbonates, although they could not be observed in the free state.

The structure of the ore, if undisturbed, is sedimentary. Light layers containing much carbonate, alternate with darker ones that are richer in magnetite. Some of the light layers are unusually distinct. They are revealed under the microscope to consist of systems of pores and cavities. It is evident that such channels favor the circulation of water. Their presence explains the progress of alteration in a horizontal direction along the layers,

as emphasized by Leith,[2] which is commonly indicated by brown streaks that lie between gray, unaltered material.

Magnetite occurs in its typical octahedral crystals, in combination with the cube, and as twins. A part of the magnetite appears, therefore, idiomorphous, *i.e.* it was the constituent which crytallized out first. Another part with quartz inclusions is idioblastic, *i.e.* it grew with its typical forms into other material.

Quartz and siderite are allotriomorphous. They are contemporaneous crystallizations.

Martite replaces magnetite, proceeding from the edge of the crystals (Fig. 1). This replacement is the first sign of an alteration of the ore. Its dependence on the depth was especially examined in the drill holes, which reached a depth of about 300 feet. The dip of the layers is gentle in these vertically drilled cores. In the upper part of the holes, the martite rim is thicker, leaving only a small core of magnetite; as the depth increases the rims become thinner. At 250 ft. in one hole, for instance, martite, is no longer present. Therefore, the oxidation of magnetite to martite proceeded from the surface to the depth of the ore body and was caused by descending water.

Black Oxidic Ore.—A dark decomposition product was observed in other drill holes, one drilling being especially examined from the top to the bottom. The black-brown upper part changes gradually with depth into the gray, unaltered type described above and is characterized by lack of siderite, which was decomposed into magnetite with martite rims. Apparently the change occurred in several steps. At first the carbonate was decomposed into magnetite, probably by the heat of a dioritic intrusion, remanents of which were observed at the top of the drill core. After this, the newly formed magnetite together with the original mineral were partly oxidized to martite by descending solutions. It is possible that the martite formation in the gray, unaltered ore, and in the heat-affected part, took place at the same time, *i.e.* after the diorite intrusion.

The original idiomorphous magnetite crystals are commonly

[2] Leith, C. K.: Secondary Concentration of Lake Superior Iron Ores. ECON. GEOL., vol. 26, no. 3, pp. 274–288, 1931.

less oxidized than the irregular masses of this mineral that have greater surfaces. This material apparently was derived from carbonate. With increasing depth in the drill hole the magnetite crystals appear better developed. Twins may be present. At a depth of 250 ft. and deeper, siderite occurs. The martite rims become smaller towards the bottom so that in a core taken from a depth of 264 ft. ferric oxide was no longer observed as a free phase.

Hydrated Ore.—Another type of alteration was encountered in several other drill cores, the identifying characteristic being a yellow and reddish-brown color. Streaks of these shades parallel the layers of gray, unaltered siderite. Commonly the alteration is quite abrupt within a few inches in the direction normal to the layers, so that well crystallized sideritic ore closely borders highly oxidized material. This illustrates again the circulation of water along the layers. In the weathered zones the carbonate is affected before the magnetite. In the beginning of the decomposition, a faint rim of oxide is formed around siderite (Fig. 4). In further decomposed samples the carbonate is entirely replaced by a structureless mass of hydrated ferric oxide that breaks out readily during polishing of the specimens.

Towards the bottom of one drill core, a zone of complete oxidation was found underlying gray, unchanged, sideritic ore. The change from the fresh siderite on the surface to the deeper decomposed portion was gradual. First, carbonate was oxidized, then magnetite was altered to martite, and finally, at a depth of about 250 feet, martite was hydrated to goethite. After the oxidation was completed, the removal of quartz was observed. Therefore, the iron content in this last stage was higher than in the less altered varieties. The beginning of alteration does not considerably influence the iron content, as the hydration counteracts the concentrating effect of the oxidation.

CONCLUSIONS.

The oxidation in the third variety with the reddish brown color was accomplished by aqueous solutions, as is proved by the ac-

companying hydration. It was probably the latest alteration, since the hydrates could not have undergone extensive pressure or a temperature high enough to have expelled the water. The black oxidic ore was formed at an earlier time.

The formation of martite in gray, otherwise unaltered sideritic ore, is distinguished from both oxidic types. Here the siderite was decomposed first and then the magnetite was oxidized; whereas, in gray sideritic ore, the carbonate is unattacked, but the magnetite is well oxidized to martite close to the surface of the deposit. Therefore one must assume that the martite formation took place under different conditions, possibly with a different solution, and before the hydrating weathering.

The manner in which the alterations proceeded agrees with this chronological order. The first oxidation of magnetite to martite started from the surface. On the other hand, the later hydrating oxidation can be found in several structures, such as folds and faults which have been formed after the older period of metamorphism and enabled solutions to reach various horizons where they could circulate along the layers.

One might suspect that the idiomorphous magnetite, the oldest form of iron oxide in the ore body, might likewise be the result of an oxidation of siderite with subsequent recrystallization having preceded the three steps of alteration described above. The differentiation of siderite and magnetite in layers of less than one millimeter in thickness, however, cannot be explained with such an assumption, but is an indication of simultaneous precipitation with varying ratios of the compounds which later crystallized to siderite and magnetite. Magnetite is indeed the most likely form in which an iron oxide is formed together with ferrous carbonate, because it is next in the order of oxidation, whereas ferric oxide is the highest oxidized stage. With an excess of ferrous iron as is the case in the sideritic deposit, one might expect the simultaneous formation of siderite and magnetite. Under more oxidizing conditions magnetite and hematite would be formed.

Carbon dioxide was probably produced by organic life or by the decomposition of organic material. It is conceivable, then, that the layers with varying siderite and magnetite contents were

produced by varying amounts of organic material. This might have been accomplished, for instance, by the seasons. In summer, when life flourished in the water, more organic substance was precipitated resulting in more carbonate, whereas in winter, iron oxides were preferably formed. Other factors might also have been involved, such as currents within the water, or depth of the lake bottom. In a shallow bay, for instance, more organic material might have occurred and accordingly more siderite might be produced. This would explain the lack of magnetite in several places in the deposit, as mentioned above.

SUMMARY.

The identification by heating polished sections of sideritic ore is described.

Magnetite is the oldest form of iron oxide in the sideritic ore of the Marquette district. A part of it is contemporaneous with siderite and quartz.

Evidence of three periods in the alteration of the sideritic ore was observed:

(*a*) The replacement of magnetite by martite, which took place along the rim of the magnetite crystals, proceeded from the surface of the ore body downward, and was caused by descending solutions, as observed in gray sideritic and black oxidic ore.

(*b*) The decomposition of siderite into crystallized magnetite-martite, a process which formed black-brown ore.

(*c*) The last, hydrating oxidation of siderite to ferric hydrates, such as goethite, which process occurred in different horizons and resulted in reddish brown ore.

ACKNOWLEDGMENT.

The writer wishes to express his thanks to the officials of the A. O. Smith Corporation for permission to publish the results of this investigation.

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MILWAUKEE, WIS.

DISCUSSION AND COMMUNICATIONS

THE ORE DEPOSITS OF THE TRI-STATE DISTRICT.

Sir: The August, 1932, number of ECONOMIC GEOLOGY contains an interesting paper by Dr. C. K. Leith,[1] entitled "Structure of the Wisconsin and Tri-State Lead and Zinc Deposits." He made several references to our paper, "The Ore Deposits of the Tri-State District."[2] A brief discussion in answer to some of the points which Dr. Leith made regarding our paper may prove of interest.

On page 405, regarding the relation of structure to ore genesis, Dr. Leith says:

> In some cases the investigator has had such a strong predisposition toward one or another hypothesis of origin of the ore that he has obviously been influenced in the selection of his supporting structural facts from the many available.

On page 417:

> Comparing these various views, it is apparent that advocates of deposition of the ore by rising waters, whether hot or cold, have desired to see evidence of deep fissures and faults controlling the runs of ore, and have not hesitated to assert definitely that such fractures exist, even though their observational evidence was of a highly circumstantial variety. Although other than structural evidence has been cited by advocates of hot rising solutions, such as assumed zonal arrangement of ores and the existence of scattered dikes in the same formations in distant areas, nevertheless the existence of deep faulting and fissuring has bulked large in their argument,—so much so that the impression has been created, particularly by Spurr, Emmons, and Fowler, that the acceptance of deep faulting carries with it a strong presumption in favor of rising hot solutions. To others there is an obvious *non-sequitur* in this argument.

[1] Leith, C. K.: Structures of the Wisconsin and Tri-State Lead and Zinc Deposits. ECON. GEOL., vol. 27, pp. 405–418.

[2] Fowler, G. M. and Lyden, J. P.: The Ore Deposits of the Tri-State District. Amer. Inst. Min. Eng. Tech. Pub. 446, 1932.

On page 418 under " Conclusions ":

> The desire to find confirmatory evidence of some hypothesis of ore genesis has clearly influenced the structural interpretations. Much of the structural evidence is therefore discredited as a sound basis for interpreting the origin of the ore. Other evidences of ore genesis are not here considered.

Evidently Dr. Leith overlooked our principal reasons for believing that the ores of the Tri-State District are from an igneous source. We state on page 36, under " Genesis of the Ore ":

> The fact that the cycle of metamorphism and mineralization was an orderly one and essentially stopped after the period of mineralization, shows that it was controlled by conditions that do not exist at the present time. This cycle, starting with dolomization and chertification of a relatively pure limestone, was followed by a period which included silicification (producing jasperoid) accompanied by the deposition of practically all of the galena and sphalerite of the district. Following this, the cycle was completed with the period of deposition of the pink dolomite, calcite, quartz crystals, marcasite, and small quantities of pyrite and chalcopyrite. Mineralization after the completion of the cycle consists essentially of the calcite and the small sphalerite crystals known as " Ruby Jack." Occasionally small galena crystals are found in the calcite. The " Ruby Jack " is possibly a redeposition of sphalerite that was taken into solution by meteoric waters, as throughout the district the earlier sphalerite shows etching.
>
> This succession of periods of mineralization has not been repeated. There is a repetition of the sequence of mineralization within any one period, but not of an early period on a later one. The evidence is conclusive that the cycle was controlled by conditions that were characteristic of the respective periods, and that these conditions changed at the end of each period.

This orderly and unrepeated sequence of the cycle of rock alteration and mineralization is to us the strongest and best evidence that we have observed in favor of the ore from an igneous source.

Fissures and fissure (shear) zones certainly do exist and are evident to anyone who will study this district in detail. We regard the fissures only as the channelways and, in some cases, reservoirs for the mineralizing solutions. They are of equal importance whether the ore is from an igneous or from a superficial source. Dr. Leith infers that we mapped and accepted the

fissuring in order to favor rising hot solutions. Careful reading of our paper should convince anyone otherwise.

We assumed it to be evident that our paper is concerned mainly with structure and its relation to the locus of the ore deposits. We have considered the origin of the ore merely incidental up to the present, and since it concerned us so little, our conclusions regarding it could hardly have influenced our observations on the major problem of ore finding.

On page 35 we state: "However, our observations in this district have impressed us with the fact that these ore bodies and the structural conditions associated with them are similar in many ways to the ore bodies in sedimentary rocks that are known to be in areas of igneous disturbance." This sentence is meant to refer to many relationships. Regardless of the sources of the ore, whether leached from sedimentary formations or from deep-seated igneous rocks, our studies convince us that the delineation, size and shape, of all the ore deposits in the Tri-State District is due to structural features of the host formations.

On page 23 we state: "Structure has a vital bearing upon metallic ore deposits in all igneous or sedimentary formations. It is the forerunner which made the channels, through which the mineral-bearing solutions traveled, and made many of the reservoirs in the host rock in which the ore minerals were deposited."

Regarding our comparison of the structural relations of the Tri-State District and Butte, Montana, Dr. Leith says, on page 415:

> Indeed, it is a clear case of extrapolation of a mechanical concept of Butte structure to a far distant and in many respects dissimilar field. Convinced of the correctness of their structural pattern and its origin, Fowler and Lyden assume that the fissures are deep-seated, and they favor the hypothesis of rising hot solutions from below, as in the case of Butte.

The fact of the matter is that we made structural comparisons only after the study of thousands of recorded observations had directed our attention to the obvious similarity between the shearing in the Miami shear trough and that of the East-West Age fissures in the Butte, Montana district. The comparisons are

more striking because the host rock here is sedimentary, whereas that at Butte is igneous. We had initially accepted the literature on the Tri-State field as a guide and commenced our studies with the notion that here was an entirely new structural problem. We were very much surprised, as others would be, to find ourselves dealing with problems the like of which we had studied elsewhere. To read into our conclusions the assumption that we have fitted the Tri-State problem into a set of preconceived ideas concerning it, hardly seems justified.

On page 415 Dr. Leith states:

> What these men describe as shear zones have been mapped by Siebenthal and Ageton as solution channels in which the Cherokee shales have been deposited, without positive evidence of faulting. The classification of fissures as shearing and tensional by Fowler and Lyden is clearly influenced by the requirements of the mechanical hypothesis which they have adopted. Others have not been able to make such classifications on the basis of observation of the fissures themselves.

Dr. Leith draws these conclusions from the work of Siebenthal and Ageton (pages 412 and 413) in the Picher-Miami field; they mapped the shale-limestone contact, an old erosion surface which does contain many sink holes in the surface of the limestone. However, this old erosion surface does not reflect the true structure of the Boone strata beneath. In some cases troughs in the limestone, as mapped by Siebenthal and Ageton, are directly over structural domes in the Boone strata as mapped by us.

In the old Joplin field Siebenthal and Smith [3] recognized strata and correctly mapped structure, using the Short Creek oölite as datum. In most areas their work is excellent.

In many parts of the Tri-State District one may observe fractures and shattered areas that are definitely later than the ore deposits. They are largely of the gravity type. By doing detailed mapping they are readily distinguishable from the premineral fissures.

On page 23 we state: "In studying the structure of the Picher-Miami field we mapped ore bodies, structural features and all

[3] U. S. Geological Survey Atlas, Joplin district folio, No. 148, 1907.

ore-bearing horizons, both horizontally and vertically, as found in the mine workings and interpreted from drill hole data. This involved the correlation of the ore-bearing horizons over a number of square miles and under all types and degrees of alteration and deformation."

Our paper contains two maps and a vertical section (Figs. 12, 13, 14, pp. 25 and 27) showing the Miami shear trough in the Angora-Blue Goose Mine. These data were prepared from underground observations and drill hole data in order to show actual conditions in the Miami shear trough. We have similar data in equal detail covering nearly 25 square miles in the important part of the Picher-Miami field. In fissure zones throughout the district vertical displacements of the strata may be measured readily, and in some areas exceed 100 feet.

Thousands of recorded observations determined the mechanical hypothesis for us; other influences were unnecessary.

On page 416 Dr. Leith discusses the Grand Falls chert and breccias and their relations to ore genesis in the Tri-State District:

> Of especial interest is the varying interpretation of breccias in their bearing on ideas of ore genesis. These are widespread in the Tri-State field, and they constitute the host for much the greater part of the ore. In earlier interpretations these were regarded as mainly friction breccias, no matter what the form of their occurrence, and this idea is carried through to the present by advocates of rising hot solutions. From the start, minor parts of the brecciation were recognized by nearly all observers as resulting from solution and slump of limestone near weathered surfaces. . . . When later, the Grand Falls chert breccia was found to extend in a great sheet down the dip into the Miami end of the field in a continuous layer 15 to 40 feet thick, roughly parallel to the bedding of the overlying and underlying sediments, it became difficult to account for it as a friction breccia, although this idea still persists among those who are trying to prove extensive faulting. . . . I had occasion to call attention to it in connection with my study in 1925 of the silicification of old erosion surfaces. . . . The evidence of the surficial origin of the greater part of the chert breccias now seems to me conclusive. Also I am entirely unable to conceive of structural deformation parallel to the bedding which could produce such results as the Grand Falls chert beds, even if the district had undergone far more deformation than is now apparent.

Chert is very widespread in the Tri-State District. It is secondary in origin, having resulted from the silicification (chertification) of part of the Boone limestone. One of the horizons in the Boone has been designated by earlier geologists as the Grand Falls chert. In the Picher-Miami field this horizon is from 35 to 40 feet thick and comprises beds, O, P, and Q, described in our paper. It is a continuous stratum but it is not a continuous chert horizon. It is chertified and brecciated only in areas of structural disturbance and gradually grades from chert and chert breccia, or both, to limestone, as the distance from the center of disturbance increases. The kind, size and shape of the breccia depend upon the degree and method of the disturbance and the character of the original rock.

Contiguous to disturbed areas the Grand Falls horizon sometimes consists of unbroken intercalated chert bands several acres in extent within the limestone. The positive identification of the beds of the Boone formation throughout the whole area is, of course, the key to any knowledge regarding the so-called Grand Falls chert. The significance of the detailed stratigraphy of the Boone is so great that it cannot be ignored by anyone presuming to understand the structure and alteration of the formation. There is nothing mysterious about the chert of this district, nor its relationship to the problems of ore finding.

The greater part of the chert in this district was formed beneath the old limestone surface—some near, some many hundred feet below. A small part of it may be of surficial origin. The areas of chert are discontinuous *laterally* and vertically and indicate numerous centers of disturbance. This is true throughout the entire Tri-State District. To account for the distribution of the chert as it actually occurs, it is entirely unnecessary to involve a great horizontal movement parallel to the bedding of the formation.

On pages 412 and 413 Dr. Leith discusses the relationship between the sub-shale surface and the ore trend. We have had the opportunity to study this supposed relationship in great detail and our conclusions regarding it are stated in the last paragraph under " Ore Deposits " on page 30:

In this district numerous attempts have been made to establish a relationship between the loci of ore bodies and sink holes in the surface of the Boone formation, sometimes marked by sink holes in the shale. Several million dollars have been spent upon this hypothesis. These expenditures were made largely for drilling. Where structural conditions formed favorable reservoirs for ore deposition in the strata beneath the depressions, ore has been found, but not otherwise. It was the structure underneath, not the sink hole itself, that controlled the formation of the ore body. In the Picher-Miami area many major ore bodies have been found under zones where the surface of the Boone formation was horizontal or even domed. As previously stated, structural conditions control the loci of the ore bodies under all conditions.

To those who are unfamiliar with this district, it may be of interest and perhaps it is pertinent to add, that our knowledge of the district, as very briefly summarized in the paper, is not the result of a few brief visits or of the study of the work of other observers, but was gained after six years of continuous observation and study during which we were aided by two or more office assistants and by a number of engineers, employed by the several mining companies, who made surveys and collected many hundred samples of drill hole cuttings for us to study. During the six-year period we have studied in detail the underground geology in more than 95 per cent. of all the mines in the Picher-Miami area. In doing this work we mapped the fissures, actually identified beds, observed rock alteration and mineralization, and established datum planes in the strata upon which to measure flexing and faulting of the beds. We critically examined and utilized these data, together with the logs of more than 18,000 churn drill holes. We compiled all these observations on maps of uniform scale for the purpose of visualizing the geologic relations of all or any part of the Picher-Miami field. Also, we studied in less detail many other areas in the Ozark Uplift.

In all cases, the evidence and conclusions presented in our paper are based upon our actual observations. We believe that others, having made the same extensive observations and given the same amount of study to the problem, would draw similar conclusions. The recorded facts are ample to speak for themselves.

GEO. M. FOWLER,
JOSEPH P. LYDEN.

JOPLIN, MISSOURI.

REVIEWS

The Miami-Picher Zinc-Lead District, Oklahoma. By S. WEIDMAN. Pp. 168; tables 26; pls. 11; figs. 12; bibliography. Oklahoma Geol. Survey, Bull. No. 56, 1932.

This report is an important contribution to our knowledge of the zinc and lead deposits of the Tri-State District.

The principal ore-bearing horizon is the Boone formation of the Osage series. The Grand Falls chert, which was considered by Siebenthal as a well defined and persistent member of the Boone, Weidman regards as extremely variable in thickness and not constituting a definite stratigraphic horizon. Unconformably overlying the Boone formation, is the Mayes formation correlated with the Cartersville of the Joplin district. This is ore-bearing to a minor extent. Weidman does not adhere to Siebenthal's interpretation of the occurrence of the ores in association with an ancient Karst topography, and states that "variations in thickness of the shale and sandstone of the Mayes formation appear to be the basis to a large extent for the erroneous belief in the widespread occurrence of 'shale holes' and shale depressions in the surface of the Boone formation." He finds no evidence that a sink-hole topography developed on the Boone surface prior to the deposition of either the Mayes or the Cherokee.

Important features of the structure include gentle regional dips which are, however, not uniform but show local warping, mostly small and without regularity. One major and one minor fold are present. The Miami syncline, trending N. 20° to 30° E. with width usually of about one-half mile, is traceable for at least 15 miles northeast of Miami and for at least 25 miles to the southwest, and affects the Mayes, Boone and Cherokee formations. A smaller fold is the Seneca syncline in the southeastern part of Ottawa County.

The fracturing which is responsible for the formation of the characteristic breccias and has so largely influenced the distribution of the ore, is believed to have occurred at three periods: first, during the post-Boone uplift, second, during the post-Mayes uplift, and third and most important, during the post-Cherokee uplift. Major fractures associated with the Miami syncline trend diagonally across the axis of this fold. The curved fracture pattern, so characteristic of many of the mines in

this district, is interpreted as a probable effect of the upward thrust of igneous intrusions as indicated later.

Most of the ore of the region occurs in a zone 50 to 100 feet thick in the lower portion of the upper half of the Boone formation. In the Picher district there is little or no typical "sheet ground" such as has been described in the Joplin district; the ores occur in "flat runs," "vertical runs" and ore pockets. Mineralization obviously took place subsequent to the deposition of the Pennsylvanian Cherokee shales and probably in Mesozoic times, "and most likely contemporaneous with the orogenic movements and magmatic activity characteristic of the Jurassic or Cretaceous periods in the outlying regions."

The cherts of the region are interpreted as of two ages. The white cherts, so abundant in the undisturbed portions of the Boone and as fragments in the breccias, are believed to have formed in the interval between the Boone and overlying Mayes deposition, this opinion being based on the presence of pebbles of these cherts in the basal conglomeratic beds of the Mayes and their absence at higher horizons. They are interpreted as replacements by thermal solutions that came from buried intrusives, but not accompanied by sulphide mineralization. The darker cherts, termed jasperoid, that form a component of the matrix of the ore-bearing breccias, are clearly younger and are interpreted also as of hydrothermal origin, though in this case chertification was accompanied by sulphide mineralization. Thus two periods of hydrothermal action are postulated, one in Mississippian times and one Mesozoic. To the reviewer, much more evidence seems necessary to establish a hydrothermal origin for the earlier cherts.

Sandstone of the Mayes formation has become hard and quartzitic by cementation near the ore bodies. Dolomitization is uncommon in the unmineralized portions of the Boone and Mayes formations but is common in the mineralized area both in open spaces and in the matrix of breccias: it is believed to have been an accompaniment of the sulphide mineralization.

In considering the genesis of the ores the occurrence of post-Carboniferous intrusives at the Rose Dome, Kansas, and Spavinaw, Oklahoma, are cited. The cryptovolcanic area at Decaturville is cited as belonging to the same category but Dake and Bridge have recently shown that the intrusion at this place is of Cambrian age. In 1930 granite was struck in a water well in the Bird Dog mine near Picher about 500–700 feet above the general level of the pre-Cambrian granite floor of the district. This granite Weidman interprets as intrusive on the basis of silification and some arching of overlying sandstones and the presence in the granite of chlorite, hydrargillite and epidote, which he regards as endomorphic effects of the intrusion. While it is quite possible that the granite is intrusive it should be pointed out that although all these

minerals may develop hydrothermally they are also common products of weathering.

The granite at the Bird Dog mine is believed to be the immediate source of the ores in that vicinity; to quote: "Although the ore is believed to be of magmatic origin it is not in direct contact with the igneous rock from which it is derived. At the Bird Dog mine the ore is about 1000 feet above the granite and between the two is rock barren of ore. . . . Between the ore deposits and the underlying intrusive magmas (represented by the granite dike) is barren rock in which the vapors issuing from the crystallizing magma were too high in temperature and pressure for condensation and crystallization." This line of argument is, however, capable of reversal; the absence of any high temperature minerals in the ores in this district and especially near the granite dike might be cited as evidence that the mineralizing solutions were not derived from a source only 1000 feet or less distant. It seems unnecessary from the standpoint of a magmatic hypothesis to postulate so proximate a source for the mineralizing solutions in the total absence of any indication of high temperatures. It may well be that the ore-depositing solutions and granite dike both came from a much more remote magmatic source.

EDSON S. BASTIN.

UNIVERSITY OF CHICAGO,
CHICAGO, ILL.

Earth History. By LUTHER B. SNIDER. Pp. 683, figs. 332. The Century Co., New York, 1932. Price, $4.50.

If "Earth History" is offered as an introductory text-book in general geology it will not serve this purpose in many colleges, because it assumes too much knowledge of dynamic and stratigraphic geology on the part of the student. On the other hand, it is an excellent supplementary text for those who are particularly interested in extending their knowledge of historical geology beyond that obtainable from more formal texts, and should serve as a fascinating volume to the lay reader who wishes to learn something about the history of the earth from an authoritative source.

The book is divided into four sections, each preceded by an "introduction" which clears the ground for the discussions that follow. The first section deals briefly with earth materials and processes, with the "keys" that have been used in unravelling the earth's history, with the way in which the earth has been built up, and the time involved in the building. There is nothing in the volume that corresponds to the discussion of dynamic and structural geology that occupies so large a portion of the conventional textbooks, but there are brief statements of the character and the effects of dynamic processes, that, however, appear to be sufficient

for the purpose of the author in outlining earth history. The second section deals with the history of the land masses, which is based largely upon the conceptions of diastrophism and cycles. This begins with a discussion of the Early Paleozoic cycle and continues successively through the period of the Pleistocene glaciation and then in a comparatively few pages discusses the pre-Cambrian series and their meaning, using the facts learned from the study of the later periods in the interpretation of the earliest ones. The section closes with brief, but on the whole satisfactory, accounts of the theories of the earth's origin, of mountain making and of climate. The third section deals with the history of living things, and the fourth section with the relations between man and his environment. This section serves as a receptacle for the treatment of items that could not be discussed elsewhere without destroying the logical development of the author's theme. It treats of "man and minerals"; of "earth tragedies," such as earthquakes, volcanic outbursts, storms, etc., as they affect the earth's surface; of "the meaning of scenery"; of the "development of the earth sciences"; of "the present aspect of the continents," which is largely a description of their physiography; and finally of the future so far as it relates to the existing conditions on the continents and the effect of changing conditions upon life.

The book is well written and well printed. Its content is well chosen, though, of course, there will be criticism of some of its parts by those who do not accept the views of some of the geologists whose writings have been used as bases for a few of the author's statements.

A very acceptable feature of the book is its wealth of excellent illustrations, many of which are entirely new to the readers of the conventional text-books.

Its author, and also its publisher, are to be congratulated on their success in producing such a handsome, entertaining and readable volume.

W. S. BAYLEY.

Man and Metals. By T. A. RICKARD. 2 vols., pp. 1061, figs. 108. McGraw-Hill Book Co., New York, 1932. Price, $10.00.

These two long-awaited scholarly and substantial volumes by Mr. Rickard represent without question his most distinguished achievement in the field of writing. They are written as only Mr. Rickard can write, in a style favorably known to our readers.

These volumes tell for the first time the full story of the part played by mining and the search for minerals, in the development of world civilization. Beginning with the days when neolithic man first dug in the chalk to find nodules of flint, Mr. Rickard traces the course of man's search for mineral wealth and shows to what extent civilization has literally followed the pick. It is not only a history of mining, and in-

cidentally of geology, but also a story of civilization to parallel that of his old fellow student, Mr. Wells, in his Outline of History.

The enticing chapter headings give us an idea of the contents. They are: (Vol. I) Introduction; The Ages without Metals; The Early Use of Metals; The Gold and Copper Mines of Ancient Egypt; The Phoenician Metal-merchants; The Cassiterides, or Tin Islands; The Athenians and Their Silver Mines; The Mines of the Romans in Spain and Italy and in Britain. (Vol. II) Mining in Mediæval Times; The Law of Mines and the Freedom of the Miner; The Conquistadores; The Later Argonauts; The Use of Coal in the World's Workshop; The First Use of Iron; Iron in Human Industry; The Miner in Southern Africa; The Romance of Modern Mining; Epilogue.

The first volume is essentially a scholarly history dealing with a romantic subject of unfailing interest to everyone, and represents the product of many years of research. The second volume carries us through mining in mediæval times to the epic adventures of the Conquistadores, the gold rush days of '49, and the great mineral strikes of the Klondike, Australia, and Nevada. Nor is the modern overlooked in his discussion of the present day gold and copper mining and iron industry.

Mr. Rickard has brought to his task not only a keen sense of the picturesque, but also a ripened scholarship that serves to make these volumes a contribution to historical writing of wide general interest. I heartily recommend it, not only to the geologist, mining engineer, and metallurgist, who should derive from it an enlightening view of the history and development of their own professions, but also to the general reader, who will not find himself entangled in technical language.

ALAN BATEMAN.

The Geological Map of Australia (in four sheets). Scale 1: 2,990,000. With accompanying Notes. By SIR T. W. EDGEWORTH DAVID. Pp. 177, figs. 10. Edward Arnold & Co., London, 1932. Price, map unmounted, 20 s.; mounted, 42 s.

The map of Australia, together with the accompanying volume of notes, is issued in advance of the author's larger work, the Geology of the Commonwealth of Australia. Inset on the map sheets are eleven sections, illustrating important features of Australian geology.

The notes are divided into sections, as follows: Physical Geology (pp. 7–21), Historical and Tectonic Geology (22–115), Economic Geology (116–144), and Details of Sections (145–162). There is a brief review of the historical geology of Australia at the end of the volume.

Most of the section on economic geology is devoted to a discussion of artesian water, coal, oil shale and oil.

It is impossible to review this work in detail, since it is, in itself, a summary. To the reviewer, it appears to be a most painstaking and up-to-date summary of the work which has been done to date in Australia. Wherever possible, the connection between Australian and extra-Australian faunas and tectonic events has been traced. Since the last geological map of Australia appeared in 1908, this map is necessary to all who are interested in the geology of Australia, not only because of the inclusion of recent data, but because of the small scale of the earlier maps.

W. V. Howard.

University of Illinois,
Urbana, Illinois.

Soils: Their Origin, Constitution and Classification. By G. W. Robinson. Pp. 390, figs. 12. Thos. Murby and Co., London, 1932. Price, 20 s.

According to its author this book is "written primarily for those who are interested in the soil as an object of study in itself, and secondarily for those whose interest lies in its economic or geographical significance, . . . but it may be hoped that the book will prove of value . . . to geologists because of the part played by the soil in the weathering cycle."

The first part of the volume deals with the origin, constitution, and properties of soils, the next part with the description of the chief soil groups of the world, the third part with the problem of their classification and geographical distribution and the remainder with soil surveys and soil analysis and a discussion of the inter-relationships of soils, plant growth and agriculture.

It is impracticable to review the book in detail. It is sufficient to declare that it covers its field admirably. The chapter on weathering, that on the nature of the clay complex and that on base exchange produced by colloids are particularly interesting. The nature of the organic matter in soils and the effect of bacterial action upon it are briefly, but satisfactorily, discussed in a chapter of 28 pages, and the water relations of soils in another chapter of the same length. About 100 pages are devoted to description of soil types and 20 pages to soil classification. The chapters on soil surveys, soil analyses and the relations existing between plant growth and soils contain interesting suggestions, but few new ideas.

The volume on the whole is an excellent summary of modern scientific knowledge of soils in general. It is of special value as an introductory text on the subject, since at the end of each chapter is appended a select bibliography for those who wish to extend their knowledge beyond that obtainable from the text.

W. S. Bayley.

A French-English Vocabulary in Geology and Physical Geography. By G. M. DAVIES. Pp. ix–140. Thos. Murby & Co., London, 1932. Price, 6s.

In reading French scientific literature, the English reader finds little difficulty in understanding the strictly scientific terms. It is the "commonplace words used in a semi-technical sense, and the wide descriptive vocabulary, varying with different writers, that are more likely to trouble an English reader." It is these words that comprise the greater part of this dictionary. Stratigraphic terms are included if they were proposed or are widely used by French, Belgian, or Swiss geologists.

The Ore Deposits of Socorro County, New Mexico, by S. G. LASKY. New Mexico School of Mines, Bull. No. 8, 1932. Pp. 139, pls. 4, figs. 21.

This is a fairly detailed account of the occurrences of metallic minerals in the county, except those of iron and manganese. In 1916 the county produced ore to the value of over $3,000,000, but in 1928 this was reduced to only a little over $108,000. A short summary of the geology of the region is given, followed by a description of each mining district, including its structure, the character of its ores, the manner in which they occur, and a brief statement of their origin.

BOOKS RECEIVED.

BY

DAVID GALLAGHER

Etudes Géologiques et Prospections Minières par les Méthodes Géophysiques. By P. GEOFFROY AND P. CHARRIN. Pp. 346, figs. 103. Bull. du Serv. Carte Géol. de l'Algérie, 4e Série, Géophysique, No. 1. Alger, 1932. General principles of the various geophysical methods and practical value of individual methods for certain cases, illustrated by examples.

Lupa Goldfield. By D. R. GRANTHAM. Pp. 29. Tanganyika Geol. Surv. Bull. 3. Dodoma, 1932. Price, 5/ .

The Kimberlite and Associated Occurrences of the Iramba Plateau. By E. O. TEALE. Pp. 7, map. Tanganyika Geol. Surv. Short Paper No. 10. Dodoma, 1932. Price, 2/ .

On the Sub-Bothnian Unconformity and on Archean Rocks Formed by Secular Weathering. By J. J. SEDERHOLM. Pp. 85, figs. 62, map. Comm. Géol. de Finlande, Bull. 95. Helsingfors, 1931.

On the Geology of Fennoscandia. By J. J. SEDERHOLM. Pp. 30, map, table. Comm. Géol. de Finlande, Bull. 98. Helsingfors, 1932. With

special reference to the Pre-Cambrian, and explanatory notes to accompany a general geological map of Fennoscandia. Fine colored geological map of Fennoscandia, scale 1 : 8,000,000.

Petroleum Geology of the State of São Paulo, Brazil. By C. W. WASHBURNE. Pp. 282, pls. 3, sketches 10, figs. 121. Comm. Geog. e Geol. do Estado de São Paulo, Bull. 22. São Paulo, 1930. With a colored geological map of São Paulo, scale 1 : 2,000,000.

The Geological Society of America, 1888–1930. By H. L. FAIRCHILD. Pp. 232, portraits 18. Published by the Society, New York, 1932. A history of the Science and the Society.

Our Mineral Civilization. By T. T. READ. Pp. 165. Century of Science Progress Series. Williams & Wilkins, Baltimore, 1932. Price, $1.00. A popular discussion of the relation of modern civilization to mineral resources, their development, and mineral industry; non-technical, interesting.

Physiography and Quaternary Geology of the San Juan Mountains, Colorado. By W. W. ATWOOD AND K. F. MATHER. Pp. 176, pls. 34, figs. 25, map in color. U. S. Geol. Surv. Prof. Paper 166. Washington, 1932.

Geology and Ore Deposits of the Pioche District, Nevada. By L. G. WESTGATE AND A. KNOPF. Pp. 79, pls. 8, figs. 13, map in color. U. S. Geol. Surv. Prof. Paper 171. Washington, 1932. Price, 85 cts. Detailed geology of these interesting silver-bearing lead-zinc sulphide replacement deposits; fissure veins in quartzite, mineralized granite porphyry, replacement veins and bed replacements in carbonate sediments through stratigraphic range of 6500 ft. Deep oxidation (1100 ft.), much manganese oxide.

Geology and Ore Deposits of the Stockton and Fairfield Quadrangles, Utah. By J. GILLULY. Pp. 171, pls. 32, figs. 22. U. S. Geol. Surv. Prof. Paper 173. Washington, 1932. Detailed description of the geology of a famous mining district. Monzonitic intrusive equivalents of the volcanics overlying the thick, folded Paleozoic sediments, caused contact-metamorphic lead-silver-zinc-copper deposits.

Physiography and Glacial Geology of Eastern Montana and Adjacent Areas. By W. C. ALDEN. Pp. 133, pls. 51, figs. 19. U. S. Geol. Surv. Prof. Paper 174. Washington, 1932. Price, $1.00.

The Ashland Coal Field, Rosebud, Powder River, and Custer Counties, Montana. By N. W. BASS. Pp. 105, pls. 35. U. S. Geol. Surv. Bull. 831–B. Washington, 1932. Detailed geological description of flat-lying Lance and Fort Union subbituminous coal, reserves estimated at 10,750,000,000 tons.

Geology and Oil Resources of the Elk Hills, California, Including Naval Petroleum Reserve No. 1. By W. P. WOODRING, P. V.

ROUNDY, AND H. R. FARNSWORTH. Pp. 82, pls. 22, figs. 8. U. S. Geol. Surv. Bull. 835. Washington, 1932. Price, 60 cts.

The Tatonduk-Nation District, Alaska. By J. B. MERTIE, JR. Pp. 107, pls. 1, figs. 3. U. S. Geol. Surv. Bull. 836–E. Washington, 1932. Price, 15 cts. Principally stratigraphy; this area affords unusual opportunity for compiling complete section; Jurassic, only system missing.

Tertiary and Quaternary Geology of the Lower Rio Grande Region, Texas. By A. C. TROWBRIDGE. Pp. 260, pls. 45, figs. 76. U. S. Geol. Surv. Bull. 837. Washington, 1932. Price, 75 cts. Detailed stratigraphy and structure of this gas and oil-producing region.

Rare-element Minerals of Canada. By H. V. ELLSWORTH. Pp. 272, pl. 1, figs. 8. Canada Geol. Surv., Econ. Geol. Series, No. 11. Ottawa, 1932. Price, 40 cts. Excellent and exhaustive treatment of the occurrence, mineralogy, and chemistry; also radio-active age determinations.

Manganese Deposits of Canada. By G. HANSON. Pp. 120, figs. 4. Canada Geol. Surv., Econ. Geol. Series, No. 12. Ottawa, 1932. Price, 20 cts. Chemistry, mineralogy, production, nature, origin, and geology of manganese; bulk of volume description of occurrences.

Investigations of Mineral Resources and the Mining Industry, 1931. Pp. 153, pls. figs. Canada Dept. Mines, Mines Branch, No. 727, Ottawa, 1932. Eight papers by various authors: sandblasting sand, helium, pitchblende-silver (Great Bear Lake), rock wool, bituminous sand (Alberta), separation of bitumen from sand, quartzite (Nova Scotia).

Feldspar. By H. S. SPENCE. Pp. 145, pls. 13, figs. 16, maps 7. Canada Dept. Mines, Mines Branch, No. 731, Ottawa, 1932. Price, 25 cts. General, World production, feldspar mines in Canada, preparation of feldspar for market, uses.

Gold in the Ontario-Quebec Boundary Region. Pp. 15, 1 map. Notes prepared by the Ontario Dept. of Mines and the Quebec Bureau of Mines for the Summer Excursion of the Society of Economic Geologists, August, 1932.

Ground Water Supplies of the Camden Area, N. J. By D. G. THOMPSON. Pp. 80, pls. 2, figs. 13. New Jersey Dept. of Conservation and Development, Bull. 39, 1932.

Preliminary Summary of Results Obtained from a Survey of Repressuring Operations in the Southeastern Illinois Oilfield. By A. H. BELL AND F. SQUIRES. Pp. 22, figs. 4. Illinois Geol. Surv., Press Bull. Ser. No. 23, 1932.

Structure and Oil Possibilities of the Warsaw Area, Hancock County, Illinois. By A. H. BELL. Pp. 17, figs. 4. Illinois Geol. Surv., Press Bull. Ser. No. 24, 1932. Detailed stratigraphic and structural data.

Copies of books mentioned under "Reviews" or under our "New Book List" (see advertisement page) may be purchased through our Journal Bookshop by writing to W. S. Bayley, University of Illinois, Urbana, Ill.

SOCIETY OF ECONOMIC GEOLOGISTS

THIRTEENTH ANNUAL MEETING.

THE Society of Economic Geologists will hold its Thirteenth Annual Meeting at Princeton University, Princeton, N. J., on July 7 and 8. This meeting occurs shortly before the meetings of the XVIth International Geological Congress, in order that an unusual number of overseas members may be present, and a cordial invitation is extended to all members of the Congress. The time and place of meeting are such that convenient arrangements can be made to attend the principal excursions before the Congress (the "A" excursions).

Papers for Princeton Meeting.

The Program Committee requests that members submit titles of papers, accompanied by abstracts not exceeding 200 words in length, at as early a date as possible. The Committee consists of the following members: E. S. Moore (Chairman), University of Toronto, Toronto, Canada; J. Gilluly, Washington, D. C.; W. H. Newhouse, Cambridge, Mass.; William M. Agar, New York City; W. V. Howard, Urbana, Ill.; and C. D. Hulin, Berkeley, Cal. Titles and abstracts should be sent to the Chairman. The number of papers accepted will be limited to that which may be presented in two days. Papers by non-members of the Society will be accepted. A further statement regarding the program will be sent to members at an early date. All persons not members of the Society of Economic Geologists may secure further information by corresponding with the secretary.

Penrose Medal of Society of Economic Geologists.

The next award of the Penrose Medal of the Society of Economic Geologists will be made to Louis deLaunay. This medal, established in 1923 for unusually original work in the Earth Sciences, has previously been awarded to T. C. Chamberlin, J. H. L. Vogt, Waldemar Lindgren, and David White. Presentation of this medal will be made at the Princeton Meeting.

SCIENTIFIC NOTES AND NEWS

Jan Versluys, of The Hague, Holland, has received the appointment of professor of economic geology and mineralogy in the University of Amsterdam.

W. L. Whitehead, consulting geologist for the Utah-Apex Mining Company, has been examining mines in the Mother Lode and Nevada City-Grass Valley districts in California.

Chester W. Washburne recently gave a course of lectures on structural dikes at the Montana School of Mines, and is expected to give a series on faulting some time during the spring.

C. J. Gray, chief inspector of mines for the Union of South Africa, has retired after 37 years of service.

E. O. Teale, who has been director of the Geological Survey of Tanganyika for some years, has retired and left Tanganyika in December for Australia.

E. T. Mellor, who has been for some time in England, has now returned to the Rand, South Africa.

Anton Gray, who has been making a geological investigation in Serbia, Yugoslavia, for Trepca Mines, has now returned to London.

Paul Billingsley, of Salt Lake City, Utah, is representing New York interests in exploration at the Nickel Plate mine at Hadley, British Columbia, which has been closed down for some months with no ore in sight.

A. E. Fath, of New York City, is now in Germany. His address is Semperhaus B–III, Hamburg 1.

Stewart Campbell, State Mine Inspector of Idaho, has retired, after twelve years of office, and his place has been taken by W. H. Simons.

Russell S. Knappen is now a member of the council of the Geological Society of America, having been appointed to take the place of the late Sidney Powers.

Frederick H. Lahee, president of the American Association of Petroleum Geologists, recently made a lengthy trip through the West and as far north as Calgary, Alberta, in the interests of the Association.

John Knox has taken the place of A. F. Brigham as general manager of the Hollinger Consolidated Gold Mines, where he has been assistant manager for some years. Mr. Brigham is now consulting engineer for the company at Montreal.

W. V. DeCamp, of Jerome, Arizona, has resigned his position as general manager of United Verde Copper Company.

F. J. Alcock, of the Geological Survey of Canada, recently delivered a series of three lectures on the geology of the Maritime Provinces, at Queen's University, Kingston, Ontario.

The Geological Society of Chicago was formed on December 12, 1932, at a meeting of some seventy geologists of Greater Chicago. The first meeting was addressed by W. J. Mead, on the subject of the Hoover Dam.

The Geological Society of America held its 45th Annual Meeting at Cambridge, Mass., December 28–30. The meetings and dinner took place in the Harvard Union and the smoker was held at "Tech." Despite the depression, the attendance was large, although distant members were few. The technical program was well arranged and ran off smoothly. The smoker unfortunately offered little time for sociability. The dinner program was an inovation in that speeches were omitted and moving pictures were presented of climbing Mt. Blanc, the Mt. Everest expedition, volcanoes in action, and the Shippee aerial photographs of South America.

A sub-committee of the National Research Council has been formed to encourage and guide further research on the origin of the lead-zinc ores of the Mississippi Valley region. New studies in the paragenesis of the ore minerals are under way; critical correlation studies of the ore-bearing horizons in the various districts have been launched under the direction of Professor R. C. Moore; the preparation of a large-scale map showing the structural features of the region will be undertaken under the supervision of Professor A. W. Giles; a field meeting of the committee for the study of critical localities is planned for September, 1933. The present membership of the committee is as follows: E. S. Bastin, chairman; E. F. Bean, C. H. Behre, Jr., G. C. Branner, H. A. Buehler, C. L. Dake, W. H. Emmons, G. M. Fowler, A. W. Giles, M. M. Leighton, W. E. McCourt, E. T. McKnight, H. S. McQueen, R. C. Moore, W. A. Tarr, S. Weidman.

The Program Committee for the meeting of the Society of Economic Geologists to be held at Princeton, N. J., next July 7 and 8, requests that Society members now submit titles of papers, accompanied by 200-word abstracts, to the chairman, E. S. Moore, University of Toronto, Toronto, Ontario. A further statement regarding the program will be sent to members at an early date.

Erasmus Haworth, professor of geology at the University of Kansas and formerly State Geologist, died at Wichita, Kansas, recently, aged 77 years.

Ernest Howe, editor of the American Journal of Science since 1926, died suddenly of heart failure on December 18, at his summer home in Litchfield, Conn.